Motorcycle Tuning for PERFORMANCE

Second Edition

Carl Shipman

street or dirt - How to make your motorcycle run better

Engine tuning
Carburetion
Ignition

Engine modifications
Performance measurement
Plus the handy RAD chart

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Motorcycle Tuning for Performance

SECOND EDITION

By Carl Shipman

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This is not a book about racing because tuning is important to any use of a motorcycle. But the popular sport of motocross symbolizes top performance—of both rider and machine. This photo shows Gary Bailey cresting a hill and getting into the following turn with typical Bailey flair. When I see a photo like this I always wonder if the rider crashed the instant after the camera clicked. He didn't. I took the picture.

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Front cover photo by Darleen Bailey shows Gary (#93) playing it cool in first-turn traffic. Poetic road-racing action on back cover was shot by talented professional, David Gooley.

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Introduction

Tuning for Performance is simply an organized approach which will help you get the most out of your motorcycle. Because it is fundamental, it applies to any kind of bike, street or dirt, stock or modified. In fact, it applies to any kind of internal combustion engine. Some of the techniques described here are borrowed very directly from automobile racing and from the drag strip.

The idea of tuning to air density is not new to professionals. If it is new to many of the people now becoming interested in getting performance out of bikes, it is because most people involved with motorcycles today haven't been at it very long.

Record-keeping also is not a new idea to professionals. It is probably the most effective "tuner's trick" and it reduces labors while improving results. Blank record forms in the back of this book will get you started keeping records, if you are not doing it already.

The book tells you how things work without assuming either that you are a practicing engineer or a technical illiterate. Somewhere in the middle ground between these extremes a good bit of theory is presented because it is useful.

Theory is linked closely with practice. Tuning adjustments are described in terms of what they do and why. Then they are described from the practical standpoint of how you adjust them and where you find them. Then they are shown in photos and drawings.

When the chips are down, we will be guided by what we see happening. An important element of rational tuning is making tests to find out what the result was. Testing gives you the only valid indication of what a tuning adjustment did and what you should do next.

This book offers you understanding of the tuning variables, practical ways to tune and test, and a method of record keeping which will help you tune better.

The payoff is more than improved performance. Tuning is an intellectual pastime, never mind the grease and grime. When you get into it, you

STREET or DIRT, performance is important. If you race motocross or on road circuits, performance of your bike and your own riding ability determine where you finish. If you just ride for fun, a well-tuned and good-performing bike gives you the fun you are looking for.

will find that you enjoy both the tuning and the results.

Stock or modified, you eventually come to grips with the same problem. Tuning it.

Stock engines are described in the owner's manual with typical carburetor and ignition settings. Then, the manual says "Of course these settings must be changed to suit climatic conditions."

When it gets down to the nitty-gritty of making your bike run well at a particular place and time, the owner's manual may not be very helpful.

The same is true of hop-up instructions. They will usually give initial settings and then say something like, "Tune for best performance." Another blank wall.

The main purpose of this book is to cut a door in that blank wall and invite you through it.

Into the domain of the individual who performs the tuning rite with his machine. Who runs well if he competes. Who climbs the hill if he tries to. Who enjoys the difference that performance makes.

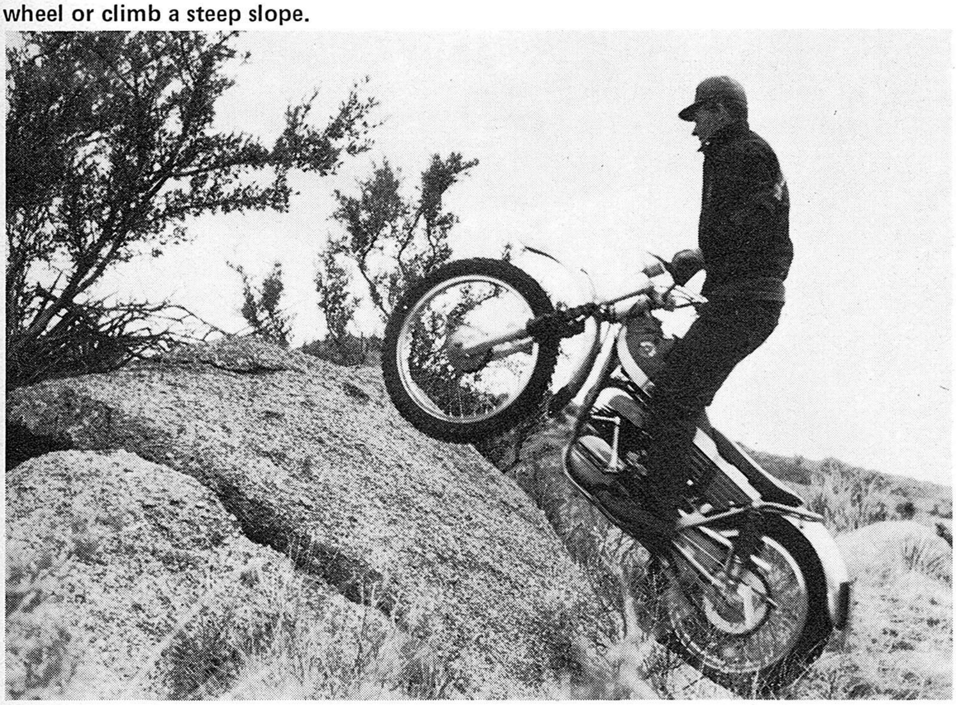
The Basic Ideas

When you get near the end of this book, you may suddenly get the feeling that tuning is a lot of hard work. It's true that it is more perspiration than inspiration. However, the more you do of it, and the more you know about it, the easier it becomes.

Some of the ideas you will find here start out sounding like more work and end up sounding like a lot less. You will make a small investment of your time in starting a set of tuning records. Very soon, your records will start saving you time and allowing you to do a much better job.

You know that if you change altitude very much, you have to rejet the carburetor. Possibly you have already done that. Jetting for altitude variations accomplishes only part of the job, but is just as much work as doing the whole job. The key is to tune to Relative Air Density (we call it RAD) using the simple chart and instructions.

At trials or on difficult trails, performance is low-end responsive power to lift the front wheel or climb a steep slope.



This is part of a Tuning Record Form. Complete forms are in the back of this book for you to use as you tune. If you record all tuning data it is easier to analyze what is happening and you don't forget some data just before you need to remember it.

You are interested in performance and have undoubtedly evaluated the performance of your bike in some way. Maybe just by riding it after you worked on it, or had it repaired. The seat of your pants isn't good enough. You may think that instrument is well above average in configuration and sensitivity, but it won't do the job if you are serious.

All human senses are non-linear. We respond to such things as heat, light, and force, in proportion to the value which already exists.

Turn on a light in a dark room and the change is large. Turn on a second light and the change is small. This means that small but significant changes in engine power may go unnoticed unless you adopt some better method of measurement.

If you have ever concluded that a bike is relatively insensitive to tuning adjustments, it is probably because you have been gaging results simply by riding.

This is worth examining a little more closely because the necessity for measurement is one of the fundamental and important points in this book.

In the field of psychophysics, researchers have attempted to measure the response of people to physical stimulus. One approach has been to find the smallest amount of change which is perceptible to an observer.

A measure of this just noticeable difference in some sensation is the amount of the change divided by the value of the stimulus before it was changed. This is called the Weber Fraction and can be written

$$C/S$$

where C is the amount of the change and S is the value before the change.

This fraction has different values for different kinds of stimulus. For weight and pressure, it runs around 1/50, or about 2%. Since these factors are close to what we observe when we sense the acceleration of a motorcycle, it appears that we should be able to sense this to about 2%. Until we read the fine print.

Psychophysical tests are made with trained observers, and the benefit of such training is to make them better able to detect small changes. In the same way, a professional racer can return to the pits and call attention to some small defect that an average rider would not notice. Let's assume we are average and raise the 2% figure to 3%.

The next rub is that this change is defined as one which the observer will detect 50% of the time. That is not good enough to guide the tuner. It would result in a "maybe-yes, maybe-no" situation which would lead maybe nowhere.

We need to know the amount of change which a rider is nearly certain to notice, if we are going to get any good out of this.

Statistical theory gives an answer. If a change is observable 50% of the time (or to 50% of the observers), then a change slightly larger than three times that value will be observed 99% of the time. *Therefore a change in performance which we are nearly certain to observe is not 3%, it is very near 10%.* When you are tuning, you just can't leave ten-percent improvements laying around because you didn't notice them.

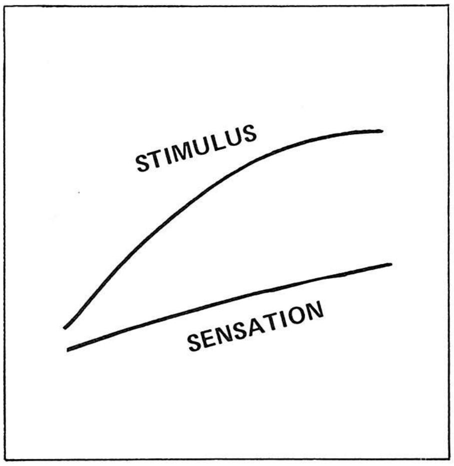
These allegations about your test instrument come from rather unlikely sources, psychophysics and statistics. However, several times as we go along, we will find other indication that a change in engine power or performance of around 10% is about as small as we can perceive with our unaided senses.

When tuning, we are never sure which way the result is going to change. It may go up or down. Whichever way it changes, if it has to vary 10% before we notice it, we are working in a dead band about 20% wide, centered on the existing condition of the engine.

Hopefully, you are by now more than convinced that measurement is the way. Tuning winds up as the search for smaller and smaller percentages of improvement. If we can't see them, we can't pick them up.

The best tool a tuner has is his notebook, and this separates the men from the boys. One adjustment often affects another and when you are playing a series of changes against each other to discover the best combination, it is impossible to remember everything you did and what the results were. Records remember for you and display data in a way that helps you.

This cherished appurtenance is not a test instrument. Tune by the seat of your pants and you will leave power laying on the shop floor. Tune by measurement and you will get it all.



All human senses follow a behavior pattern as shown by these curves. The sensation we receive from some outside stimulus does not increase in proportion to increases in the stimulus. If the stimulus is acceleration of a motorcycle, the performance has to improve a lot before we even notice it just by riding. Some method of testing and measuring is better. Several ways of testing are described in the text.

The Tuning Problem

The reason tuning is not simple is that there are several variables and they interact with each other. There is a best combination, but no amount of slide rule work will find it. The professionals and the factories tune by measuring results because there is no other practical way. Let's take a first look at the things to measure and adjust.

POWER

We can say that power is the main variable—the end result of tuning. However even that isn't simple. You can try to get extreme power at high RPM, or a broad power band, or even chug power at low RPM, depending on the type of bike and what you intend to do with it.

It may be that the tuning problem is not lack of power but the way it comes on—or goes off. Such as bogging on a hill, hard starting, missing at speed, or whatever the thing is doing wrong. In general, when you get the power right for the type of machine you are tuning, all of the characteristics of that power will be right.

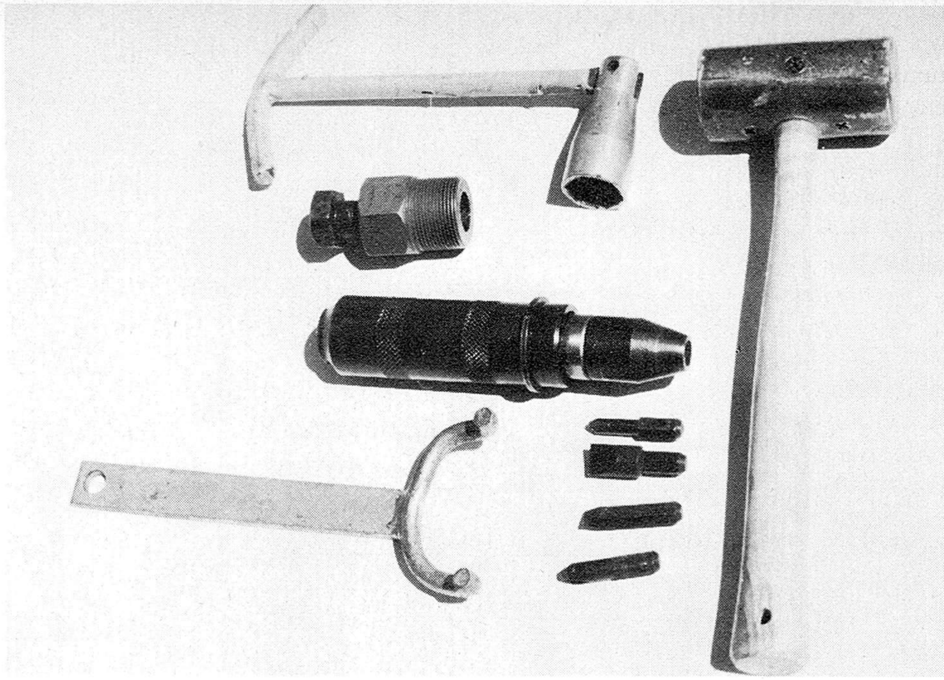
Of course you know that what an engine makes, basically, is torque. Power is simply a manifestation of torque. We have some paragraphs on that later.

F/A RATIO

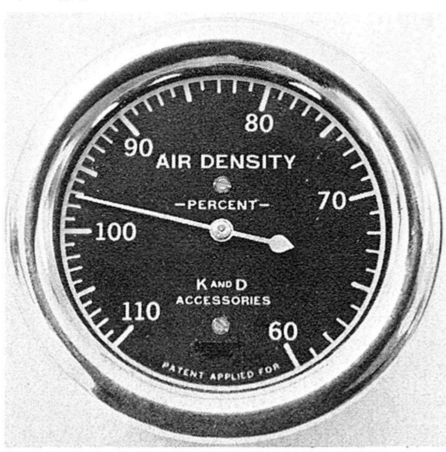
Another variable is mixture strength, or fuel/air ratio. The F/A ratio needs to be different for different operating conditions. There is the stoichiometric ratio and that dazzling word means an F/A mixture, according to chemistry, such that all of the fuel combines with all of the oxygen and none of either is left over.

We will discover that this is a philosopher's dream and that engines hardly ever operate with the "chemically correct" ratio.

We will explore the relationship between F/A ratio and the power characteristics of an engine, the cooling of the engine, and we will look into other legendary ratios such as maximum-power and maximum-economy F/A mixtures.



Tools of the tuner—Some of the tools needed to take a bike apart without causing more problems than you fix: spark plug wrench or socket, flywheel puller, impact driver with bits, flywheel holder, and a soft mallet made of hide or rubber, which you use for gentle persuasion.



It is easy to calculate relative air density from barometer and temperature readings, but many tuners prefer the K & D Air Density Meter as a guide for selecting the correct main-jet area. Air density changes from hour to hour—day to day—and most certainly from one week to the next. The meter is available from K & D Accessories, P. O. Box 276-H, Longview, WA 98632. A similar meter is offered by Moon Equipment, 10820 S. Norwalk Blvd., Santa Fe Springs, CA 90670.

AIR DENSITY

Air density is vital to the power of an engine because what is burned is mainly air. F/A ratios run from around 1:17 to 1:8 and anything in this range is combustible if conditions are right.

This means one pound of gasoline to 17 pounds of air, or 8 pounds, or something in between. The part of air which burns is the oxygen content, which is about 20%.

Air density is influenced by both altitude and temperature and can be measured in units of weight and volume, such as pounds per cubic foot. It can be expressed as a percentage of sea-level density, by using RAD numbers, or the percentage can be read by a meter.

When air is less dense, it is not possible for a normally-aspirated engine (not supercharged) to produce as much power as it does when air is more dense.

IGNITION TIMING

Somebody set the timing on your bike. Maybe you did. If the engine has mechanical ignition points, somebody will set timing again, and again, as the point set wears.

If your bike has electronic ignition, the timing may not change due to wear, but it may not be right anyway. Electronic ignitions are a great improvement over

those with mechanical points, but they wind up to be not much better than the tuner who sets them. They can be improperly timed just as easy as any other type.

Timing affects power, heating, detonation, and pre-ignition. Timing is affected by F/A ratio, temperature, compression, the fuel being used, air density, and the design of the engine.

Factory timing is good for one set of conditions, but not all sets of conditions. It is nearly as easy to set timing for best performance as it is to set it to some arbitrary number.

COMPRESSION

Compression pressure has a direct effect on engine performance. It should be measured periodically and restored when it has dropped below an acceptable value.

There are no tuning adjustments which will restore lost power due to lost compression.

GEARING

Gearing affects performance. It doesn't make sense to tune right and then run with improper gearing.

Since gearing has a definite influence on the way a bike uses the available power, gearing will be discussed in a later section. It is easy to change if the desired change can be accomplished between sprockets. The results can be surprising.

PUTTING IT TOGETHER

The foregoing was not intended to scare you or persuade you that such complicated matters had better be left to the experts. When you use the methods of this book, and practice some, you will become as expert as anybody. You can start pretending that you tune by supernatural ability.

This was intended to persuade you that the way the variables interact is complicated and that getting this orchestra to play all together and in harmony takes method, measurement, records, and understanding. Hopefully, you'll get it all right here.

MEASUREMENT

Since the variables interrelate with each other, it is important to try to separate them, so you can see the effect of each one, singly. This means you

SUGGESTED IGNITION SETTINGS

PENTON-SACHS ENGINES

100cc	2.6 mm to 3.2 mm	B.T.D.C.*
125cc	3.0 mm to 3.5 mm	B.T.D.C.

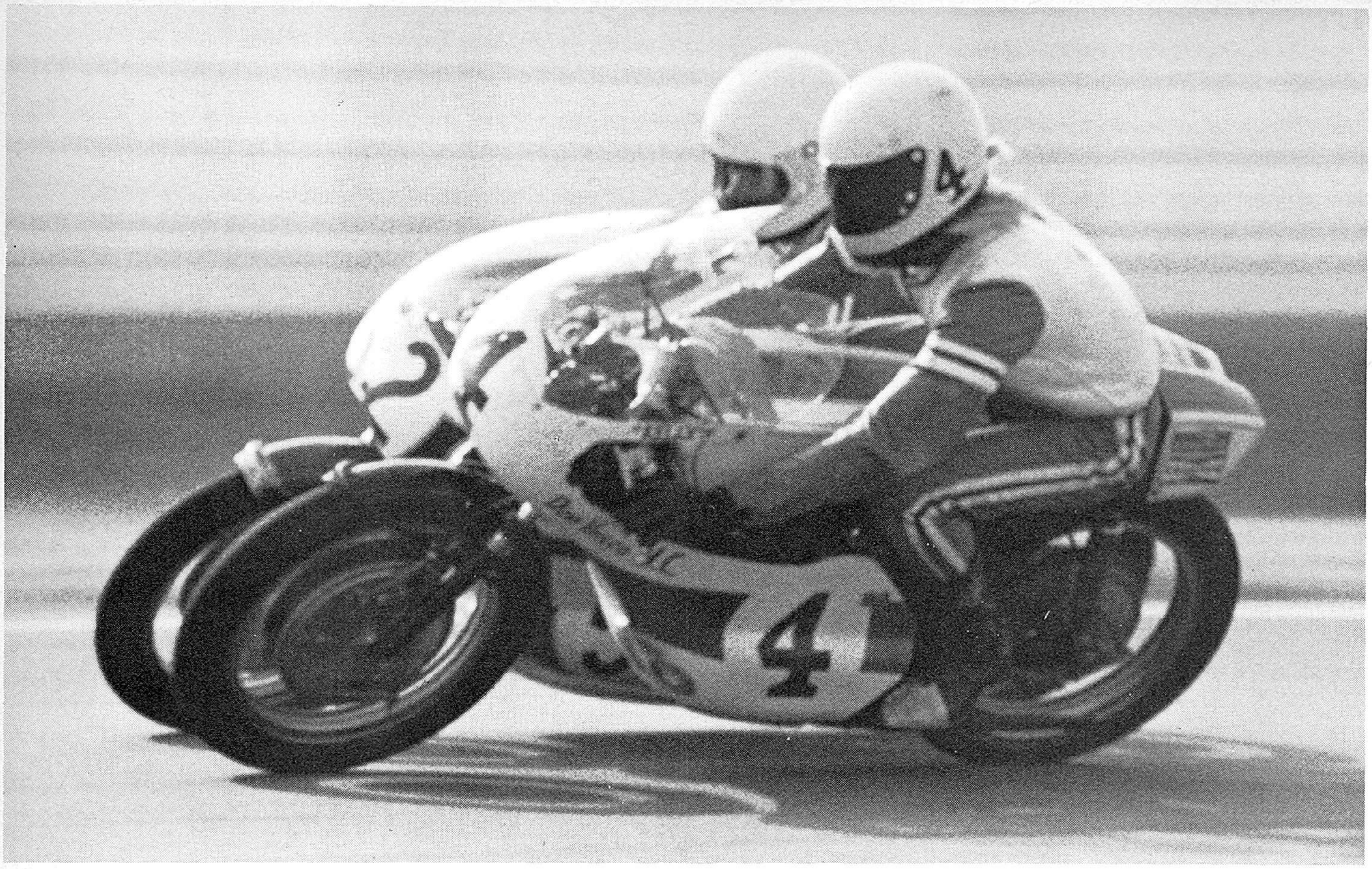
HUSQVARNA ENGINES

250cc	Approx. 3.0 mm or 22°	B.T.D.C.
360cc	Approx. 3.5 mm or 22°	B.T.D.C.
400cc	Approx. 3.5 mm to 3.75 mm or 22° to 24°	B.T.D.C.

*Before Top Dead Center

It must be understood that these are suggested settings which we use but each racer or competitor may have his own settings for the particular application of the engine.

Ignition timing instructions which come with an accessory electronic ignition suitable for the bikes listed. The important information in these instructions is the last sentence.



change only one thing at a time, and measure the result of that change.

As shown by the example later in this book, this technique will allow you to improve performance to the best possible under any set of conditions. And, when you reach that point, *you will know it.*

PERFORMANCE MEASUREMENT

This is a brief mention of some methods of performance measurement, so you can start thinking about how you are going to do it.

RACING JOE

It is good for your ego if you beat Joe, but that is not good enough for tuning. Riding technique may be involved. You may make a better start or a better turn than Joe, or vice versa.

The state of tune of Joe's bike has nothing to do with the setup of yours. Even if you beat him, it does not mean that your bike is running as well as it can. It only tells you that you won and, on that day, Joe's bike may even be sick.

Racing against Joe is not the way to tune. It is the way to enjoy the payoff from tuning.

Better ways to measure performance include:

Dynamometer
Drag Strip
Stopwatch
Accelerometer
Instruments on the Bike.

These methods are discussed in section seven, with emphasis on use of a stopwatch which is practical, accurate, and easy to do.

Why another tuning book? This book begins where the others stop. Lots of books tell you how to set up your bike to the standard numbers in the manual. But they don't tell you why, or what's going on in there, or what to do if the standard tuning procedure doesn't seem to work.

This book gives you both how and why. With understanding, you can tune for performance. When the manual seems ambiguous, or doesn't tell you enough, we fill in the gaps.

With the information in this book, you are freed from simply following instructions. You adjust, observe results and, because you know what is happening, you make the best settings for your particular bike on that particular day.

Tuning for Performance is one step beyond tuning to the manual.

The Variables

After circling the problem as we did in preceding sections, it is now time to get into details. This section discusses both theory and practice. It will tell you, for example, what you need to know about carburetors and ignition and also how to go about adjusting them.

Power is the result. We need an understanding of what power is in order to appreciate the relatively complex process by which an engine makes power.

FORCE

The pressure on the top of the piston, due to combustion, is a force which can be measured in pounds. Since the piston moves in a straight line, up and down in the bore, its motion is called *linear* (meaning along a straight line), and the force producing that motion can be thought of as a linear force.

Force can exist whether there is resulting motion or not. You can push on a building and it won't move.

Conflicting information? If you read two publications on the same subject, you are likely to find statements in conflict.

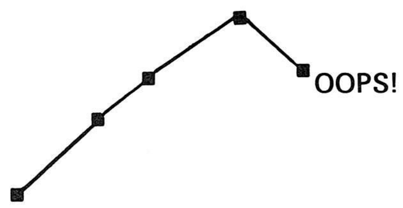
You may wonder which is right, but this does not exhaust the possibilities. *Both may be wrong.*

It is more likely both are right in some limited way. The problem may be that the author said too little, or the reader inferred too much.

The literature on ignition timing and carburetion is filled with conflict. It is likely that the reports are correct for a particular type of engine or set of conditions but the observations are not the same because engines and conditions differ.

It is also likely that most of the basic facts about engines are known today. Bluntly, theory will lead to a correct answer if the right theory is applied and *all of the conditions are considered.*

Which is why this book begins with the basics.



Secret technique—Used by every successful tuner . . . whether he admits it or not.

WORK

If force causes motion, the result is called work, which is expressed by stating the amount of force and the distance through which it acts (or moves). A common unit is foot-pounds. If a force of 20 pounds acts through a distance of 20 feet, the work done is 400 foot-pounds. Notice that nothing has been said, yet, about how long it took to do that.

ENERGY

Work is equivalent to energy and they are interchangeable. If you lift a box onto a shelf, you have done work on it, or put energy into it. The work or energy is the weight of the box multiplied by the height it was lifted, expressed in foot-pounds. An eight-pound box, lifted two feet, receives energy of 16 foot-pounds.

The energy is simply stored in the box, due to its increased altitude. This form of energy is called *potential* energy because it just stays there and is potentially available whenever you want to use it.

If the box falls off the shelf, the static, potential energy changes to energy of motion, called *kinetic energy.*

When the box hits the floor, both the box and the floor will deform some amount and the internal friction of the materials will cause some heat, even though imperceptible to you. The kinetic energy was changed to heat energy.

Energy never disappears. It is only changed from one form to another or one place to another.

Potential energy can exist in many forms. Position is one. Heat is another. Pressure is another. If a bottle blows out its cork, or combustion pressure in an engine causes the piston to move, that is pressure-energy being changed to kinetic energy.

AN EXCITING DRAMA

Chemical potential energy exists in gasoline and oxygen. When they burn or chemically react in an engine, an interesting chain of events takes place. Heat energy results from the reaction. Heat doesn't make the engine go round. It just makes everything get hot. Some of the heat causes that part of the air which didn't burn to expand and exert more pressure.

The pressure energy in the hot gases pushes on the piston and creates linear movement. The connecting rod and crankshaft convert this to rotary movement of the crankshaft.

When the clutch is being engaged, it slips, transmitting some of the mechanical energy and converting some of it to heat again because the clutch plates get hot.

The gearing changes the speed of the rotating parts, absorbs some of the energy in friction-heat, and passes on the rest of the energy.

The tire has some traction against the surface and can therefore exert a force against the surface. This force causes a linear movement of the bike. It may also cause the speed of the bike to change, which is acceleration.

The air resists movement through it, and air friction takes some of the energy away as heat in the air. If the vehicle climbs a hill, some of the energy becomes potential energy. You can park on top of a hill and, later, get the potential energy back by coasting back down the hill. You don't get it all back because some is lost in air, tire, and bearing friction.

When it's all over, every bit of chemical energy in the fuel and oxygen can be accounted for. The part that combusted

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Yes, the going is a little heavy along here— These fundamentals provide a good base for understanding later on when we get to the interesting stuff.

If you remember these things, you are welcome to skip ahead. If you're not sure, it's only a few pages.

Performance is what you do with it—Young man on chauffeur-driven Honda returning from spy mission to nearby Little League field. We wish he would treat himself as kindly as he does his driver, and get himself a helmet.

wound up either as heat or energy of position.

The part of the gas and air that went out the exhaust without burning still contains its chemical energy.

Let's back up because we skipped over torque completely in all that excitement.

TORQUE

The linear force on the piston causes the crankshaft to turn and there is some difference in a force which causes rotation. The difference is that the effectiveness of the force depends on how far it is applied from the center of rotation. If you grab a wrench farther out on the handle, you can break loose a tight nut. The same number of pounds of force will have a different effect depending on the length of the lever arm. To express this effect, we use the idea of torque. Torque is a rotational force, or one which tends to cause rotation. It is measured both by the amount of the force and its distance from the center of rotation.

Twenty pounds of force, applied at a distance from center of three feet would produce a torque of 60 pound-feet.

Torque is not work and it is not power. It is simply a rotational force. If it causes something to move, then it does work the same as a linear force acting through a distance. The only complication is that the distance is along a curved path.

The formula for work is the same whether the path is straight or curved:

Work = Distance x Force.

When things are rotating, we have to remember that the circumference of a circle is equal to pi (3.1416) times the diameter.

In an engine with a very long stroke, the circle followed by a crankpin could be 6" in diameter, or 3" radius. A force of 80 pounds applied at a radius of 0.25-foot (3") produces a torque of 20 pound-feet.

If that force rotates the crank through one revolution, then the distance traveled (6" x 3.14) is about 18.8 inches—call it 1.5 feet. The work performed in that one revolution is 120 foot-pounds.

POWER

Work is the idea of a force acting through a distance, without regard to the amount of time required. If Joe picks up a box every two minutes, and you pick one up every minute, you are doing twice as much work as Joe. The amount of work you will accomplish in a period of time will be double.

This implies that we can measure the rate of doing work. We do. It is called power.

Power is the time-rate of doing work, figured by taking the amount of work done and dividing it by the time required.

$$\text{Power} = \frac{\text{Work}}{\text{Time}} \quad \text{or,}$$

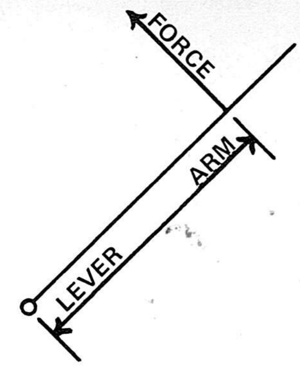
$$\text{Power} = \frac{\text{foot-pounds}}{\text{second}}$$

There is no reason we could not all live happy lives describing power in terms of how many foot-pounds per second it is, and not get somebody's horse into the act.

However, an English gentleman did that and nobody was smart enough to ignore it. He decided that some horse could lift 33,000 pounds one foot in one minute, and announced that this rate of doing work would be one official horsepower. This rate of doing work can also be expressed in seconds, and is 550 foot-pounds per second.

When you are not doing anything more exciting, you can take the rated horsepower of your bike along with the weight of bike and rider, and figure out how fast that amount of power should lift you and machine straight up. If you remember a little trigonometry, you can figure out how much power is consumed in riding up hills of various angles.

What an engine makes is torque. The torque makes work, and the work makes power. Chasing this train of thought is important to understand both how engines work and the torque and power relationship.



TORQUE = FORCE x LEVER ARM

Torque is made in the engine by the force of the piston applied to the offset "throws" of the crankshaft. The amount of offset of the crank is the lever arm. The torque is increased by gear reduction enroute to the rear wheel.

The symbol $\sim$ should be read "is proportional to." It means about the same thing as =. We use $\sim$ to simplify the presentation of ideas in the form of equations.

For example, if x = abc, then x will be doubled if a is doubled, or b, or c. The term x is proportional to each of the three, a, b, and c.

If we are concerned with the relationship between x and c, we can ask a and b to step aside, temporarily. We can then say $x \sim c$.

That is not the complete story, but it tells the relationship between the two variables we are interested in: x is proportional to c.

The benefit is to unclutter our mathematical statements, leaving out constants and sometimes other variables, so we can see a particular relationship more clearly.

When torque is applied to a crankshaft, and the crankshaft turns, the amount of work done is proportional to the distance traveled around the circular path—in other words to the amount of rotation.

EFFECT OF TORQUE ON POWER

We can say, then, that

$$\text{Work} \sim T \times R$$

where T is torque, R is rotation in degrees or revolutions or radians, and the symbol ~ means "is proportional to."

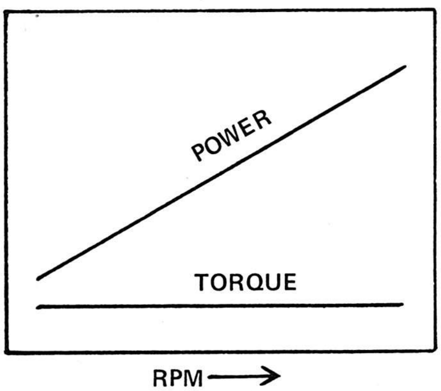
Since power is work divided by time, the power of an engine can be expressed as

$$P \sim \frac{T \times R}{\text{minutes}}$$

which is the same thing as

$$\text{Power} = \text{Torque} \times \text{RPM}$$

If the torque of an engine were the same at all speeds, and it were drawn on a graph like this:



This is the proverbial "flat" torque curve.

the torque characteristic would be a straight horizontal line.

Power would simply be the torque multipled by the RPM at each point along the graph. Since the RPM value increases steadily along the bottom axis, the power curve would be another straight line rising upwards at some constant slope.

In the real world, torque curves are not flat. At low RPM, the valves or ports are open for a relatively long time during each engine cycle, and you can expect that the cylinder will get pretty "full" of air from the outside.

As speed increases, the effect of inertia of the moving columns of gases going into and out of the engine begins to appear. If there is inlet and exhaust tuning (there is always some even if the designer didn't put it there) then the tuning takes effect at some medium to high RPM. The result is improved breathing and improved torque.

At high RPM, beyond the peak of the torque curve, the inlet and exhaust time durations become very short and do not allow good breathing. The torque drops off.

As torque begins to taper down, one would expect power to fall off. However, when torque is diminishing slowly, as RPM continues to increase, the higher RPM can still cause more power, even with slightly less torque.

When torque is decreasing at some rate, and RPM is increasing at that same rate, their product becomes constant and the power curve becomes "flat" or horizontal over some range of RPM. This is the peak of the power curve.

Beyond the power peak, torque is falling faster than RPM is rising, so the power curve takes a nose dive.

By examining torque-power curves for real engines, you will see that the power curve is simply a distorted copy of the torque curve, with the peak at a higher RPM for reasons just discussed. By the design of the engine, and to some degree by the way it is tuned, the shape of the torque curve is determined along with the RPM at which it is maximum. This also shapes the power curve.

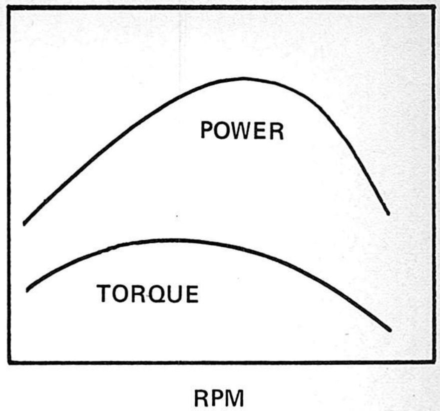
Engines for different purposes are deliberately caused to have appropriate torque curves for their intended use.

Superbike—Rides up tall buildings.

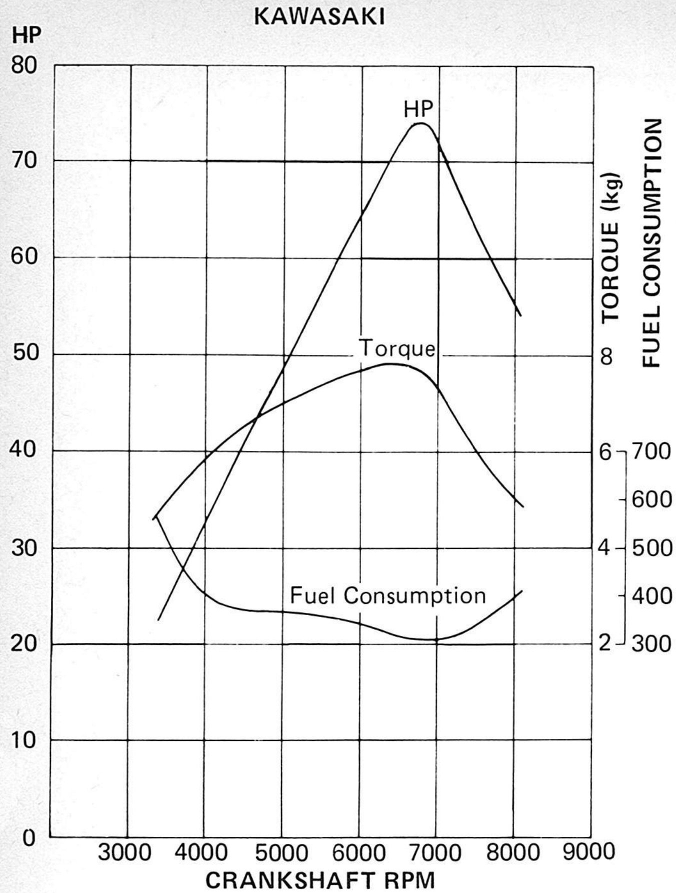
1 HP = 33,000 ft-lbs/min
= 550 ft-lbs/sec

If you and bike together weigh 550 pounds, and bike has 20 HP, then it will lift you both straight up at 20 feet per second. About fifteen miles per hour.

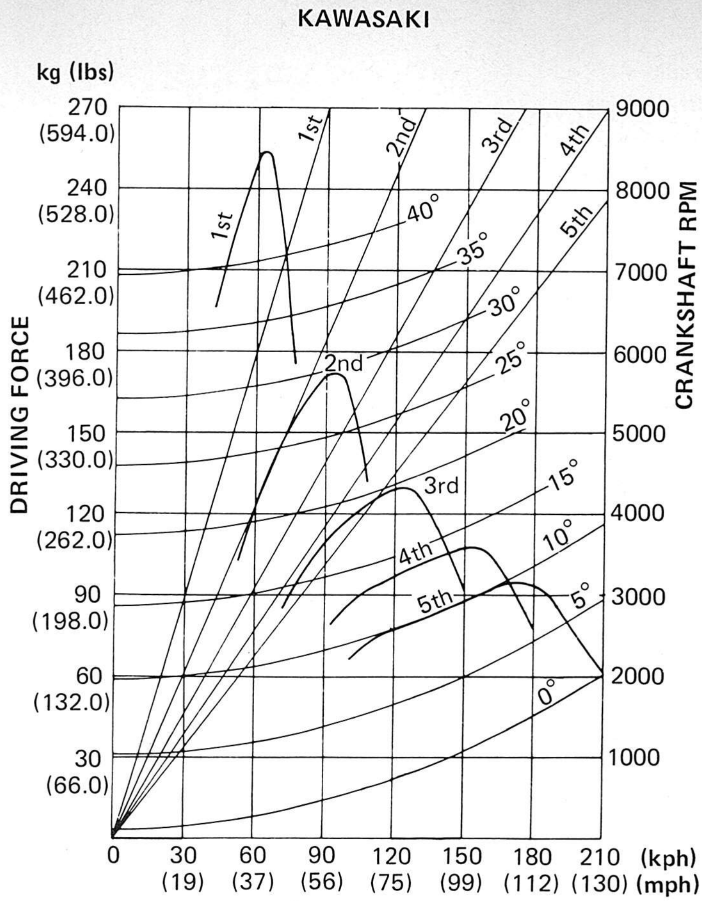
If there were traction, you could ride up tall buildings at 15 MPH.



Power at any engine speed is equal to the torque at that RPM *multiplied by* the RPM value. The power curve is therefore a distorted copy of the torque curve. Because torque rises to a peak and then drops off, power does the same but at a higher RPM.



H2 ENGINE PERFORMANCE CURVES



H2 RUNNING PERFORMANCE CURVES

ENGINE PERFORMANCE CURVES

This is engine output at the crankshaft, not rear wheel. The HP and torque curves rise to 74 HP at 6,800 RPM and 57 pound-feet at 6,500 RPM. RPM scale is across the bottom, HP scale is on the left, and two scales are on the right. The torque scale runs from 2 to 8 and is labeled kg (kilograms—actually kilogram-meters). 7.9 kilogram-meters on the torque scale converts to 57 pound-feet of torque.

The second scale on the right is fuel consumption in grams per horsepower-hour. Note that maximum fuel economy occurs just above the power peak. Elsewhere in this book, we show the maximum economy point as being below the power peak, which is true for engines in general, but not necessarily for every engine.

Two-strokes lose fresh mixture out the exhaust port, which generally accounts for the poorer fuel economy of two-strokes. When the exhaust system is resonant, one effect is to "ram" some of this mixture back into the cylinder just before the exhaust port closes, making the engine more efficient at that RPM. It is likely that this is the reason for the reduced fuel consumption shown at 7,000 RPM.

RUNNING PERFORMANCE CURVES

There is a lot of information on this chart. The data is based on rear-wheel torque and power.

The straight lines, fanning out from zero, show road speed versus engine RPM in each gear. They are read using the right-hand scale (RPM) and the bottom scale (speed).

The peaked curves show driving force (between the tire and the surface) in each gear. These curves are read using the left-hand scale and the bottom scale.

Force at the rear wheel is equal to the engine torque (at a particular RPM) multiplied by the overall gear reduction (in a particular gear) and the result divided by the rear-wheel rolling radius. From which losses in the gear train should be subtracted.

The first-gear curve shows a driving force of 550 pounds at a speed of about 40 MPH. With a light-weight rider, bike and rider would weigh about 550 pounds. If there were traction, he could ride this superbike straight up at 40 MPH!

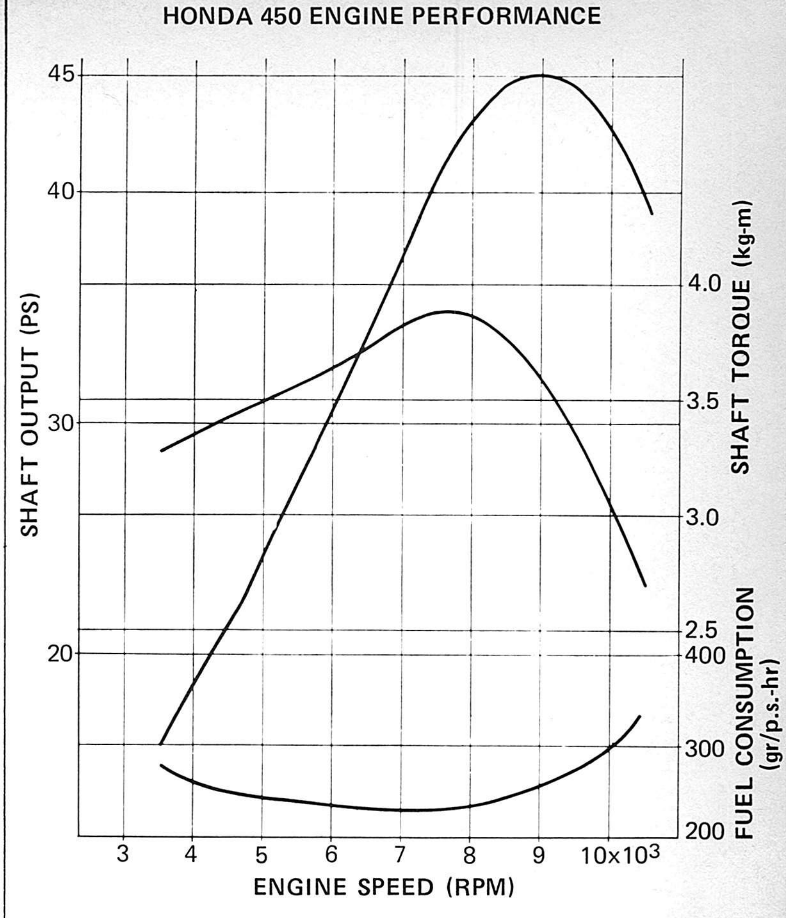
Returning to the real world, the peaked curves show available driving force in each gear. The lines marked in degrees show the driving force required to climb the indicated

gradient at the indicated road speed, read off the bottom axis. These required-force curves slope upward to show the effect of wind resistance. This shows that first gear can easily cope with a 40° slope and fifth gear will barely pull on a 10° hill.

The peak of each force-curve should occur at an RPM near the torque peak of the engine, and would be exactly at the torque peak if there were no gear-losses. To check this, project vertically from the peak of a force curve to the RPM curve for the same gear. Then read RPM off the RPM scale. For example, from the peak of the second-gear force-curve, move up to the second gear RPM curve (straight line) and then across to the RPM scale, where you read 6,500 RPM approximately. Same for each of the other sets of curves.

The maximum speed, in fifth gear on a level road, is shown to be about 130 MPH at an RPM of about 7,800. This is well above the power peak of the engine and shows that, at 100 MPH, on a level road, the machine has excess power!

We mentioned above that the bike will *barely* pull a 10° hill in fifth gear. Look again. The road speed at which the bike has enough available push to run up a 10° hill is about 100 MPH.

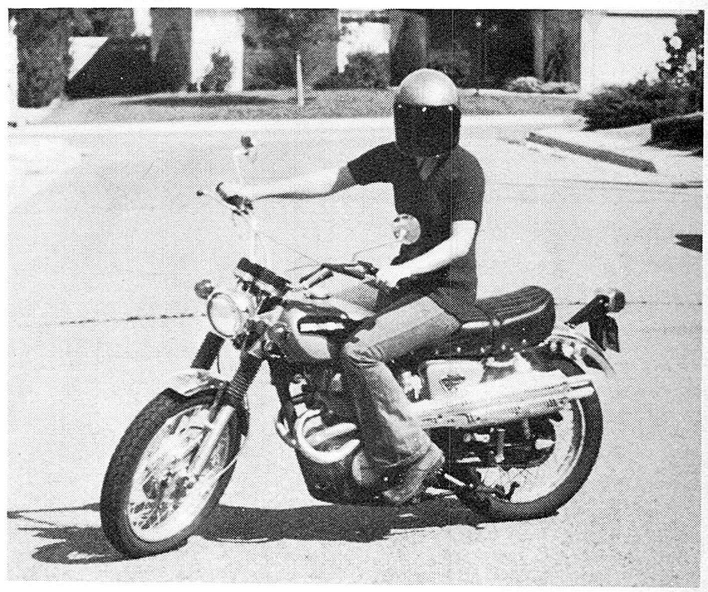


CB450 ENGINE PERFORMANCE CURVE

(Courtesy American Honda) shows maximum economy point back where we think it oughta be. This bike is no tiddler, either.

KAWASAKI H2

HONDA CB450



CARBURETION

There are just a few things you *have to know* about your carb. They relate to the way mixture ratio is controlled at different throttle settings.

As air is drawn through the carburetor due to "suction" from the engine, it picks up gasoline which joins with the air flow to provide the combustible fuel-air mixture. The throttle slide is pulled up by the throttle control cable. When it is lifted up, it allows a larger air passage into the engine and it runs faster.

There are four adjustments which affect the mix of gas and air:

idle system
throttle slide cutaway
needle setting
main jet.

When the throttle slide is all the way down, the main air passage is nearly closed. A tapered needle is fastened to the slide with a clip and the needle goes up and down with the throttle slide. When the slide is all the way down, the needle extends downward through the needle jet as far as possible and, in most carburetors, also extends into the main jet. The main jet is submerged in gasoline and is at the bottom of the tube leading up to the needle jet.

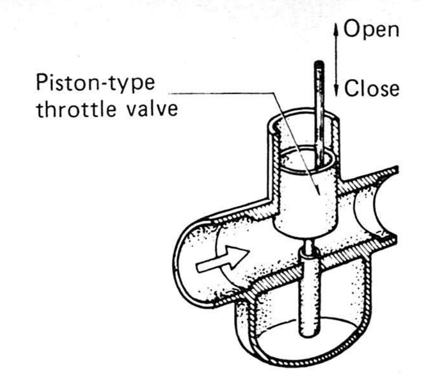
When the throttle is closed, the engine draws idle mixture through a separate system which is essentially a separate carburetor built into the body of the main carburetor.

There is a hole on the front of the carb which takes in a small amount of air. This passage tunnels over to the float chamber and picks up some fuel through a separate orifice called the pilot jet, or idle jet.

The idle system delivers mixture into the main carburetor passage through very small holes in the bore of the carburetor which experience vacuum when the throttle is closed, or nearly closed.

If there is only one opening from the idle system into the main bore of the carburetor, it will be behind the throttle slide. When the slide is closed, the high vacuum behind it draws idle mixture from the idle system.

If there are two openings into the venturi area of the carburetor, one will be called the by-pass, and the other the idle outlet. The idle outlet serves the idle function as described above.



A typical motorcycle carburetor regulates air flow by means of a piston which moves up or down in the main air passage, controlled by the cable from the twist-grip. More common names for this piston are throttle-valve and throttle-slide. When the throttle-slide is pulled up as far as it will go, the carb admits maximum fuel and air into the engine.

The tuner works with—
Fuel-air ratio
Ignition timing
Compression
Air density
Gearing
and good maintenance!

The by-pass is located so that if the throttle slide were completely closed, it would be blocked off. If the slide is then lifted a small amount, the fuel-air mixture from the idle system starts flowing through both outlets. The main purpose of the by-pass outlet is to aid the transition from idle to normal running conditions.

In the idle air passage, there is a screw which adjusts the amount of air flowing into the idle passage. The position of this screw, along with the size of the idle jet serve to regulate idle mixture.

Set the idle-air screw for a smooth idle, according to your owner's manual. Usually it will be around one and a half turns out.

There is normally a separate adjustment, called the throttle-stop screw, which limits the downward travel of the throttle slide and keeps it from closing completely.

The throttle-stop screw is normally adjusted for idle speed and the idle-air screw is used to set idle-mixture ratio.

As the throttle slide is lifted up, by rotation of the twist grip, the idle system will gradually cease functioning, the engine will receive mixture through the main passage of the carburetor, and regulation of the F/A ratio will be done by the tapered needle as it moves up and down in the needle jet.

To aid transition from idle to the normal mode of operation of the carburetor, an adjustment is provided. This is the taper of the lower forward edge of the throttle slide, called throttle-slide cutaway. A larger amount of cutaway will cause a more lean mixture as the throttle setting is moved away from idle.

In the middle range of throttle slide travel, the relationship of the needle with the needle jet is the adjustment for F/A ratio. This is accomplished by moving the clip at the top of the needle, fitting it into a different groove on the needle. There are usually three, four, or five grooves. Moving the clip to a higher groove effectively lowers the needle and reduces fuel flow through the needle jet.

When the throttle is fully open, the main-jet size is varied to establish a satisfactory F/A ratio.

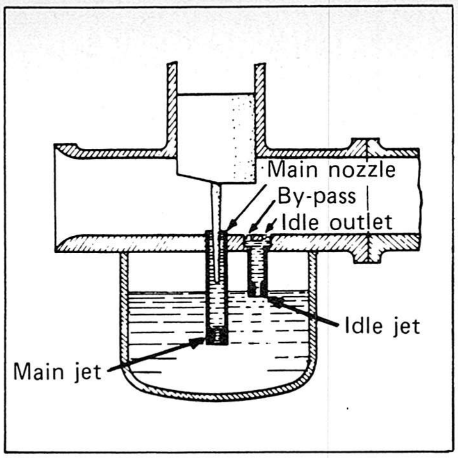
By "reading" spark plugs, according to the method described in section seven, an idea of mixture can be obtained. If the plug looks like it has been too hot, the F/A ratio may be lean provided ignition timing is not too far off. Providing a richer mixture will aid cooling.

Spark-plug readings taken at full throttle and half throttle can be used for preliminary tuning and carburetor settings changed as indicated.

That's about all you really have to know in order to do a fairly good job of carburetor adjustment. You know where the adjustments are, what they do, and how to make them richer or leaner. Other data in this book will help you decide which way to go, and you should be able to do it.

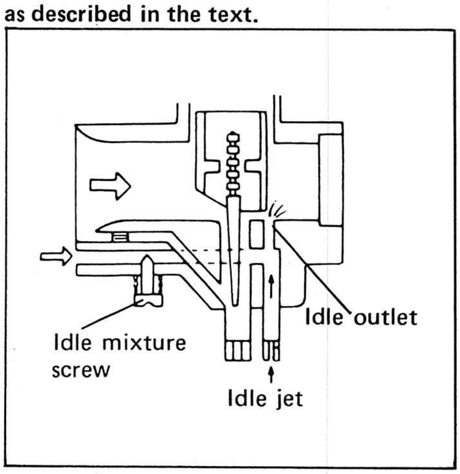
However, it helps a bunch to know more than that, so you can interpret effects that you observe and tune more intelligently.

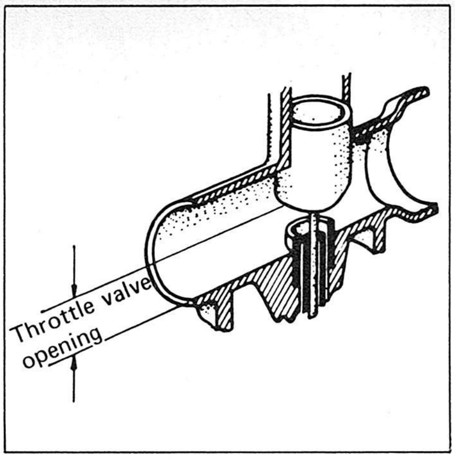
The next few pages are devoted to basic carburetor and combustion theory.



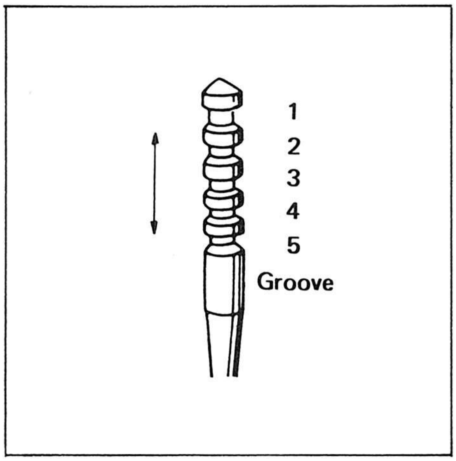
Fuel joins with the main air stream through the carburetor in two ways: through the main jet and the passage above the main jet or through the idle jet. When the throttle slide is closed, the idle system predominates. When the slide is lifted up, the main fuel system comes into use.

The complete idle system draws in air from a small opening near the front of the carburetor. The amount of air flow is adjusted by the idle mixture screw which is also called the idle air screw. The purpose of this adjustment is to set fuel-air ratio at idle speeds and this is the only adjustment for idle mixture except changes in the size of the idle jet. The combined idle air and idle fuel are drawn into the main air passage at a point behind the nearly-closed throttle slide. Another adjustment which is not shown limits the downward movement of the throttle slide. This is called the throttle stop screw and its purpose is to set idle speed by allowing more or less outside air to duck under the throttle slide and join with the idle mixture. A tapered needle is fastened to the throttle slide by a clip in one of the grooves in the needle. This is used for mid-throttle mixture adjustment as described in the text.

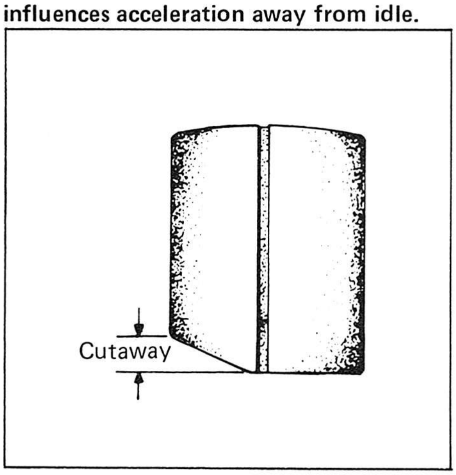


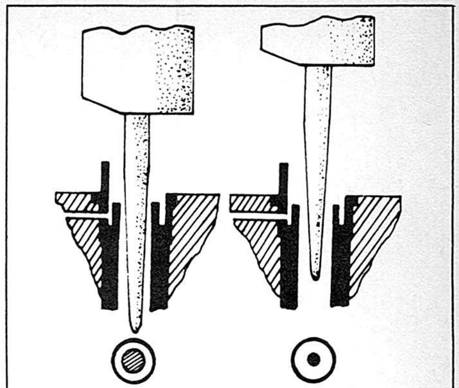


The mixture adjustments are each effective at some amount of throttle opening. You can judge the amount of opening by looking into the carb and noting how much the throttle slide is lifted above its lowest position.



Throttle-slides are tapered toward the front of the carburetor as shown and the amount of taper is known as "cutaway." Cutaway influences acceleration away from idle.





Clearance between needle jet and jet needle

The tapered needle works as a fuel valve as it is moved up and down because it obstructs more or less of the opening of the needle jet. When the needle is moved downward, into the jet, fuel flow is reduced.

The tapered needle is positioned by placing a clip in one of the grooves near the top of the needle. Sometimes shop-manual instructions say to position the needle in groove number 4. Needle grooves are always numbered from top to bottom as shown in this drawing. Number 4 means the fourth groove down from the top.

The need for performance measurement— Since you got this book by buying it, borrowing it, or worse, you are obviously interested in performance. If you have tried your hand at performance improvement, you may have been frustrated.

When you follow some instructions, or copy what someone else did, and the results are bad or indifferent, time and money was wasted.

It may be that you have overlooked performance measurement as an essential part of tuning. A principal theme of this book is that measurement and adjustment are inseparable parts of tuning.

If you have never tried it, you are going to be delighted when you do. Careful and accurate testing tells you what's going on, which direction things are going, and what to do next.

BURNING AIR

Imagine that an engine has stopped, with the intake passage open and the piston at the bottom. The cylinder is "full" of air and the volume of air is the same as the volume of the cylinder itself plus the combustion chamber in the head, which is a little more than the displacement of the piston.

The volume of air inducted is not the important thing. It is the weight of air (and the corresponding weight of fuel) which determine the amount of chemical energy present and therefore the power capability of the engine.

If we assume that we will always arrange carburetion so there is enough gasoline present to burn with the oxygen in the air, then we can say that it is simply the weight of inducted air which governs the power of an engine.

Air density may be defined as weight per unit volume, such as pounds per cubic foot. For a particular volume, such as a cylinder full,

$$W_a \sim D_a$$

where W and D denote weight and density and the subscript $_a$ means air.

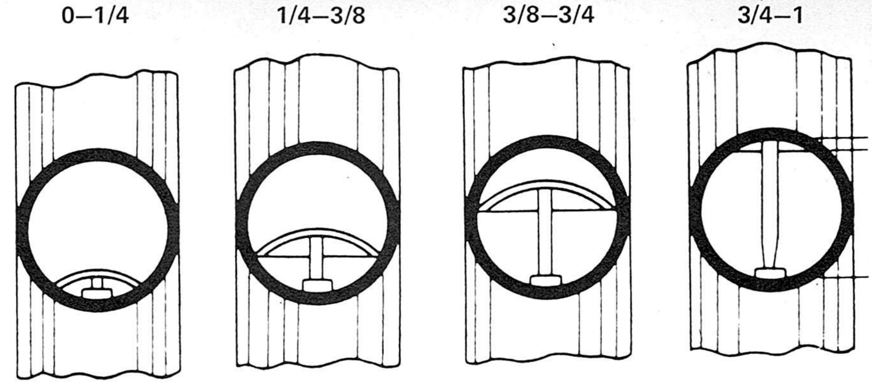
Anything which causes a change in air density will change the weight of the volume of air drawn into the cylinder and, therefore, affect power.

One thing which does that is the throttle, although most people don't think of it that way. When the intake is open for only a short period of time, a partially closed throttle will limit the air flow into the cylinder. Whatever amount of air does get in, of course, expands to fill up the volume. The result is reduced density of the air in the engine.

Another factor influencing air density inside the engine is the air density outside the engine. Outside air density is determined by both air temperature and air, or barometric, pressure.

Air becomes less dense at higher altitudes because the air at any level is compressed by the weight of the air above it. At sea level, air is compressed by the weight of all the atmosphere.

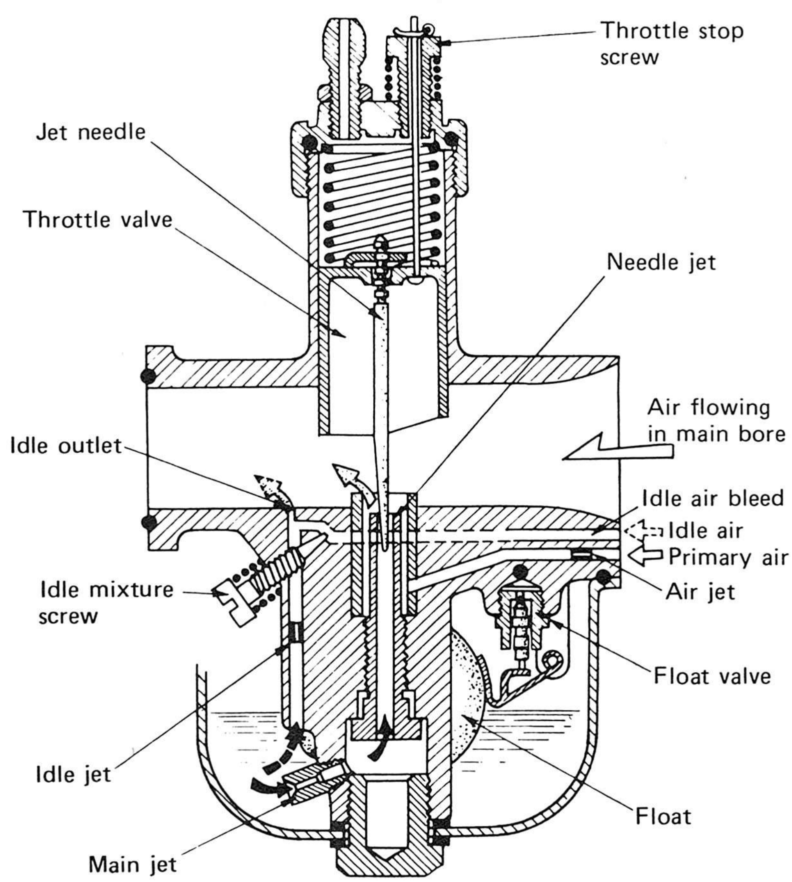
At 10,000 feet, the air is compressed only by that part of the atmosphere which is above 10,000 feet, and therefore is "thinner."



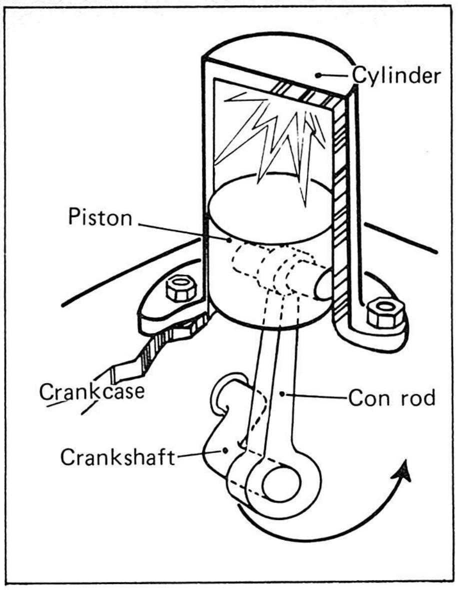
THROTTLE SLIDE POSITIONS

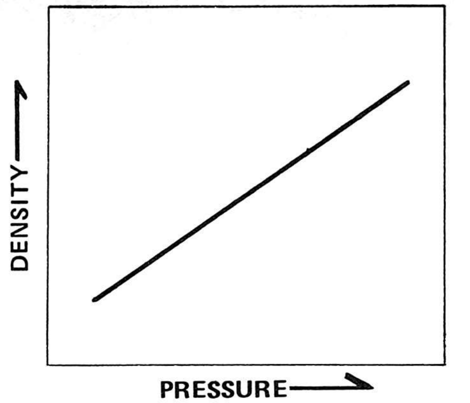
These are the positions of the throttle slide at which the various carb adjustments are most effective. From left to right: Idle is affected by the idle-system adjustments. Acceleration off idle is affected by throttle-slide cutaway. Mid-range operation is affected by the position of the tapered needle. Open throttle operation is affected by the size of the main jet.

Cross-section of a typical motorcycle carburetor. Other carburetors will vary in mechanical details but not in functions. All jets, systems and adjustments are shown here.

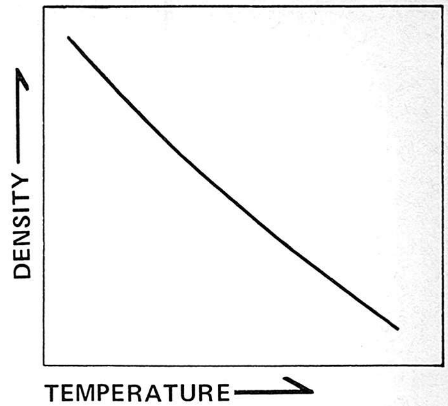


CARBURETOR OPERATION





As barometric pressure increases, air density increases. Higher air pressure can be due to lower altitude or weather conditions—either way a given volume of air will contain more oxygen.



When the air temperature goes down, density goes up and each cylinderful of air contains more oxygen.

EFFECT OF ALTITUDE

Atmospheric pressure is measured and customarily stated in "inches of mercury" or Hg. One type of measuring device uses a column of mercury which changes height according to pressure. The most convenient way to express pressure is simply to state the height of the column.

At sea level, barometric pressure is normally around 30 inches of mercury which is also about 15 psi. In the lower atmosphere, up to around 10,000 feet, the pressure will drop about one inch for every thousand feet increase in altitude. At 6,000 feet altitude, normal air pressure will be about 24 inches of mercury.

It is convenient, at any altitude, to think of the change in pressure as a percentage of the pressure at sea level. Thus, six inches drop, as a percentage of the sea-level value of 30 inches, is 20%. Density will be down 20% and the power capability of an engine will also be down 20%, no matter what you do, short of supercharging or using oxygen-bearing fuels.

Let's not confuse this with rejetting. It is necessary to rejet a carburetor at higher altitudes in order to restore a proper F/A ratio. For reasons which will be explained later, when the air becomes less dense, a carburetor tends to meter fuel so that there is an excess of fuel and a rich mixture.

Jetting down to get a proper mixture makes the engine run better, but can never restore sea-level power. If the carburetor is not adjusted for the reduced air density, the power loss will be even more because the F/A ratio is nowhere near optimum.

It works both ways. If an engine is tuned for 6,000 feet, and taken to sea level, the power capability increases. However the engine cannot produce the higher power until more fuel is provided to burn with the increased weight of air. If not rejetted, the engine will run lean, heat up, and possibly burn plugs or seize.

EFFECT OF TEMPERATURE

Riders customarily rejet for altitude, but many ignore the temperature effects of similar magnitude. At any altitude, air density is affected by temperature in addition to barometric pressure.

Again, it is convenient to express the change as a percentage. The only complicated part is that we have to use a different temperature scale.

In theory, air becomes more and more dense as temperature drops until, at some very low temperature, it has contracted to nothing. This temperature is called absolute zero.

On the Fahrenheit scale, absolute zero is at - 460 degrees. There is another scale, with intervals the same size as the Fahrenheit scale, but with numerical zero down at absolute zero. This scale is called Rankine.

Since we consider air to start expanding at absolute zero, its density is determined by how far its temperature is

---

The organization of this book—The behavior of an engine is simple when you look at one thing at a time. It is complicated when you put it all together.

We look at each tuning variable individually, and from several points of view. We consider its function, how it performs the function, and how to adjust it.

There are sections which take different points of view. One discusses the effect of the variables, another how to measure them, another how to adjust them.

If you find that you seem to be hearing echoes as we go along, it is because we consider each variable more than once before we tie it all together and say, "Here's how to tune for performance."

---

above zero, Rankine. Densities are inversely proportional to temperatures:

$$D_1 \div D_2 = T_2 \div T_1$$

and,

% Density change = % Temp. change.

To convert from Fahrenheit to Rankine, simply add 460 degrees to the Fahrenheit reading.

If air temperature changes from 50 to 100 degrees Fahrenheit, we can calculate the percentage change in density as follows:

$$\frac{460 + 50\ \mathrm{F.}^\circ}{460 + 100\ \mathrm{F.}^\circ} = \frac{510\ \mathrm{R.}^\circ}{560\ \mathrm{R.}^\circ}$$

$$= 0.9$$

$$= 90\%$$

The air density at 100° is 90% of the density at 50°F.

COMBINED EFFECT

Since both temperature and pressure affect air density, it makes sense to look for a way to show the combined effect.

We can do this by use of the *ideal gas law*, which will be used more than once as we go along. This law states the behavior of perfect gases and gives a good indication of what happens to real gases. It says:

$$\frac{PV}{T} = K$$

where P is pressure, V is volume, T is temperature, and K is an unvarying constant number.

We can write this as:

$$V = \frac{KT}{P}$$

Since density is defined as $W \div V$, then V is $W \div D$, and this can be substituted for V in the ideal gas law, above.

$$\frac{W}{D} = \frac{KT}{P}$$

Solving for D,

$$D = \frac{PW}{KT}$$

or $$D \sim \frac{P}{T}$$

which tells us, simply that density increases with an increase in pressure, and decreases when the temperature goes up.

By putting the correct constants in the density equation, we can get one which will allow us to calculate actual air density at some temperature and pressure.

However, we are normally not concerned with the actual air density. We only need to know how much it has changed, in percentage, so we can make appropriate adjustments to the engine.

This simplifies the whole deal and allows us to use an invented number called RAD, which means Relative Air Density, and which can be read off a graph.

The RAD number (or actual air density) is very significant to the tuner. When an engine is tuned best for a particular RAD, the settings can be recorded, along with the RAD number. When that RAD repeats on another day, even at some different combination of pressure and temperature, the former engine settings will again be the correct ones.

Changes in RAD also provide definite indications of which way to change tuning adjustments.

To read RAD numbers off the chart here or on the back cover of this book requires knowledge of both temperature and local barometric pressure.

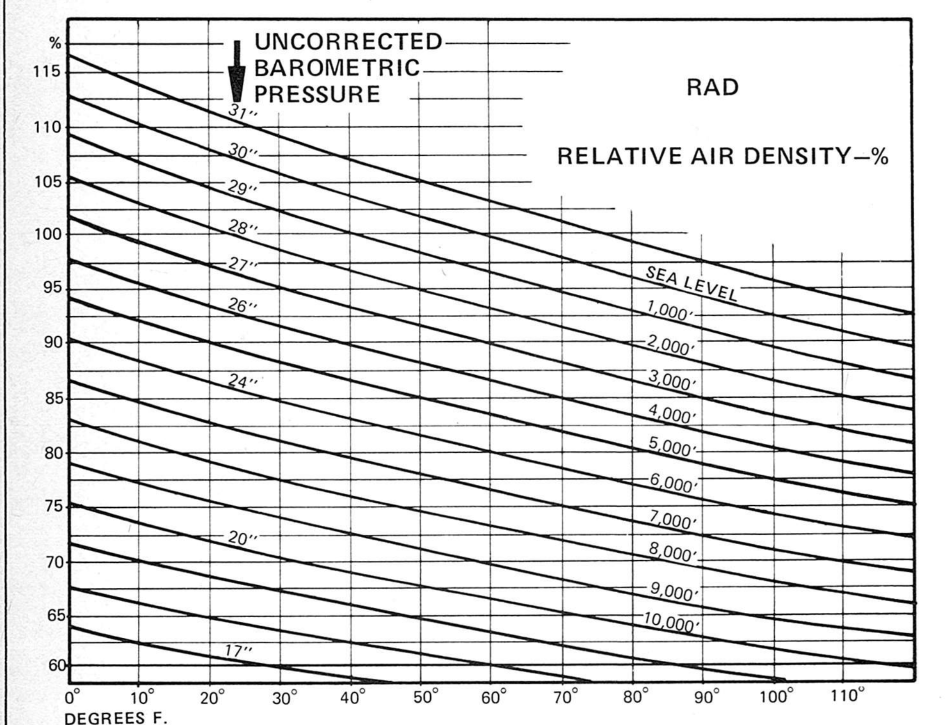
Unless you have your own barometer, there is a ringer in finding pressure. The weatherman announces a barometric pressure every day and says whether it is going up or going down. This pressure is "corrected" or "reduced" by the Weather Service, which means that they pretend the entire USA is at sea-level pressure.

They report variations around the assumed sea-level figure to show the local highs and lows which are part of weather data. The purpose of weather reports is to tell you what the weather is doing rather than to tell you every day what the altitude is.

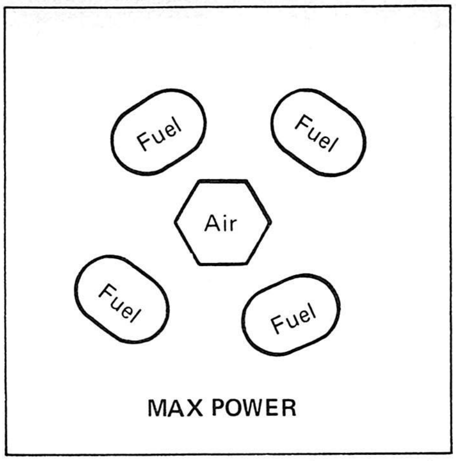
What is needed is actual pressure, not the corrected reading. You can get this fairly closely by taking the weather-report value and subtracting one inch of mercury for every thousand feet above sea level, up to about 10,000 feet.

The uncorrected pressure at any Weather Service location is called the "station pressure." You can get this by call-

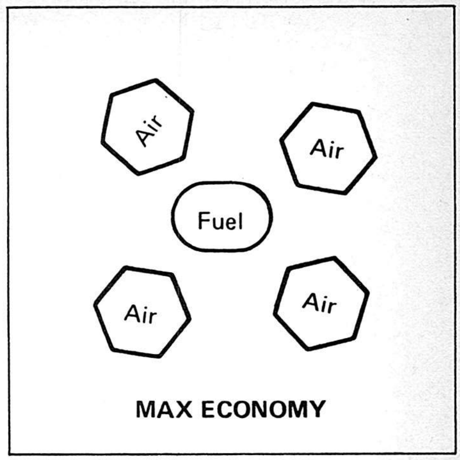
This chart gives you Relative Air Density at any combination of barometric pressure or altitude and air temperature. The RAD chart agrees closely with air-density meters and serves the same purpose—to help you tune for best performance on a particular day.



RAD CHART



A maximum-power mixture has excess fuel to be sure all molecules of air are burned—or at least as many as possible.



A maximum-economy mixture has excess air to combust as much fuel as possible.

ing the station and asking them for it. If the man gives you the same pressure that you see on TV, and you are not at sea level, explain that you want the uncorrected barometer reading.

If you get a recording, do not bother to discuss the matter. The phone book will have another number which connects to real live people.

Every altitude has some normal barometric pressure which can be thought of as the *vertical* change in pressure. This normal pressure for any locality is altered by the weather fronts which move across the country. Weather changes can be thought of as *horizontal* or *time* variations in normal pressure. These variations are included in the weather reports and are the reason the local pressure changes from day to day.

USING THE RAD CHART

To find Relative Air Density at your location, enter the chart from the bottom, at the temperature of the day where you are.

Move vertically up to the curve which represents your local uncorrected barometric pressure. Local altitude is normally close enough, and the curve can be selected by altitude, if desired.

From that intersection, move horizontally over to the RAD scale and read the number.

At 90°F., and an altitude of 3,000 feet, RAD is 85%. The air density is only 85% of what it would be under standard conditions at sea level.

If the temperature drops to 60°, at that same altitude, RAD goes up to about 90%.

VENTURIS AND MIXTURES

Cycle riders get more intimately involved with carburetors than most people. We have some rules that we go by:

1. The fuel-air ratio must be correct for good performance.
2. The F/A ratio influences engine cooling.
3. Running rich is better than running lean.
4. Larger carburetors require much larger jet sizes.
5. Operating at higher altitudes requires smaller jet sizes.

These rules are all correct and for each there is a reason.

We are also frequently offered the information that there is a chemically-correct fuel-air ratio called stoichiometric, and that it is near 1:15.

As a magic number, this 1:15 is virtually useless and there is no need to scratch it on the side of your tank. Your engine never read any chemistry books and, what it does is simply to combine molecules of gasoline with molecules of oxygen as well as it can.

What you do is help it, never mind whether the ratio is 1:15 or not.

In fact, you hardly ever want the magic 1:15 ratio. You want the mixture to be richer than that at small throttle openings, at full throttle, and maybe even in between.

After dazzling us with the word "stoichiometric," many books then go on about maximum-power ratios and maximum-economy ratios.

These ratios are really just names for two different ideas.

Assume you are after maximum power. Considering the contribution to power that is made by the gasoline and by the air, the air is considerably more important. The power of an engine is limited, basically, by how much air we can get into the cylinder and how well the oxygen component is burned.

The maximum-power idea is to surround each molecule of oxygen with lots of molecules of gasoline, ensuring that it will combine with one of them and be burned. Following that idea to its logical conclusion, when all of the oxygen is burned, there will still be some molecules of gasoline left. A maximum-power mixture is therefore richer than 1:15 and may be around 1:12.

The max-economy

Fuel and air are used in different ratios according to what the engine is doing. Engines tuned for minimum emission of pollutants are set to run leaner than this chart indicates except under heavy load and starting.

Running Condition	Mixing Ratio (Weight Ratio) Air : Fuel
Starting	1-3 : 1
Idling	8-10 : 1
Low-speed Running	12-14 : 1
Light-load Ordinary Running	15-16 : 1
Heavy-load Running	12-14 : 1

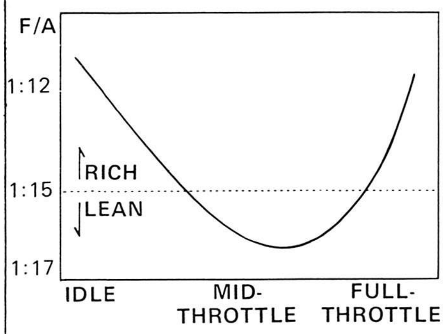
philosophy will now be obvious. Since gasoline costs money and air is free, a person can choose to try to burn all of the fuel by inducting excess air. Then, the mixture will be leaner than 1:15. Maximum torque, or power, cannot result from this mixture, but that was not the objective.

Ratio curves illustrating these ideas are common in the literature and can lead to a misconception unless it is understood that the main purpose is to illustrate the ideas, rather than show some way you have to set up an engine. Often it is a good way to set up, because it matches the cooling needs of an engine at full and mid-throttle.

On the supposition that a rider who cranks the throttle wide open must be looking for power, the curve gives him the max-power ratio. The excess fuel helps to cool the engine.

At half-throttle, or thereabouts, the ratio tends toward lean, or max-economy, and is less than 1:15. The supposition is that the rider is just cruising along, is not generating much heat in the engine, and would rather have good gas mileage and enough money left to buy a hamburger.

At small throttle openings, the mixture should be rich for reasons discussed below.



TYPICAL FUEL/AIR RATIOS

Another way of visualizing what the carburetor has to do. At both idle and full-throttle the mixture should be richer than the chemically-correct 1:15 ratio. In the mid-range the mixture can be lean for economy. When you want performance you open it up.

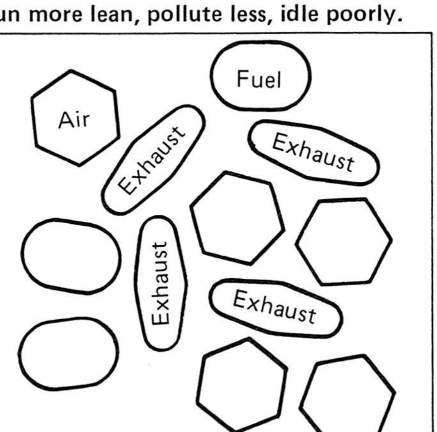
IDLING MIXTURE PROBLEMS

When the throttle is opened only a small amount, the charge of fuel-air taken into the cylinder is small. There is not much gas rushing into and out of the combustion space during the inlet and exhaust events. The general result is that a higher proportion of exhaust gas remains in the chamber to "pollute" the next serving of fresh mixture.

When small amounts of fresh charge are being drawn in and burned, the compression in the cylinder is low at the end of the power stroke. When the exhaust opens, the burned gases don't rush out with vigor, and they loiter around to interfere with the next combustion cycle.

Due both to expansion and time the exhaust products remaining in the cylinder are relatively cool and they mingle among the fresh charge molecules, holding them apart and absorbing heat. This "patchy" mixture is the main reason for the lumpy idle of two-strokes.

One problem at idling speeds is residual exhaust from the preceding cycle which interferes with normal combustion of the new charge. Remedy is to dump in excess fuel to give the fuel molecules a better chance of pairing up with oxygen molecules. Problem is, this pumps excess hydrocarbons into the atmosphere. Solution is, run more lean, pollute less, idle poorly.



IDLING MIXTURE

To help this situation, we play the numbers game and put in too many gasoline molecules so they can better compete with the burned gas molecules for the attentions of the oxygen.

Under some conditions, the F/A ratio which works well at idle will not even burn at full throttle.

THE FISH HOOK

Since we face the prospect of running rich at times, there is an interesting "fish-hook" curve which helps the tuner. This is a plot of power versus F/A ratio, assuming a fixed throttle opening and RPM. In other words, under fixed conditions, it shows the effect of mixture on power.

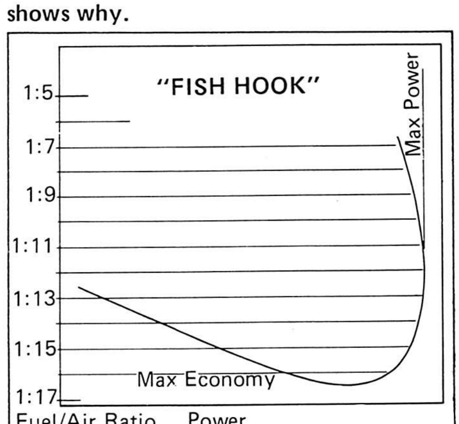
The easiest way to understand this curve is to start at the point of maximum power and observe that, if the mixture is caused to be either rich or lean from that point, power is reduced.

The reason power is reduced, going lean, is that there are not enough gasoline molecules to combine with all of the oxygen molecules.

The reason power is reduced, going rich, is a complexity. The chemical reaction between gasoline and air requires some elevated temperature to start it, after which it should generate sufficient heat to maintain the burning process.

Combustion moves outward from the point of origin (the spark plug) just like a grass fire spreads from the burning match that started it. Each part of

A very good rule for tuning is to find the carburetor main jet which causes obvious signs of richness. Maximum power will be one or two jet sizes smaller. This curve shows why.



MIXTURE LOOP AT CONSTANT RPM

the periphery of the flame front raises the temperature of the adjacent fuel to the combustion temperature. If the grass is green, wet, or not present, it won't burn.

Similarly, if there are an overabundance of fuel molecules in the combustion space, they tend to insulate one set of burning fuel-air molecules from the next set and prevent the transfer of heat outwards to unburned mixture. This leads to incomplete combustion of the air and possibly pockets of mixture which never burn at all.

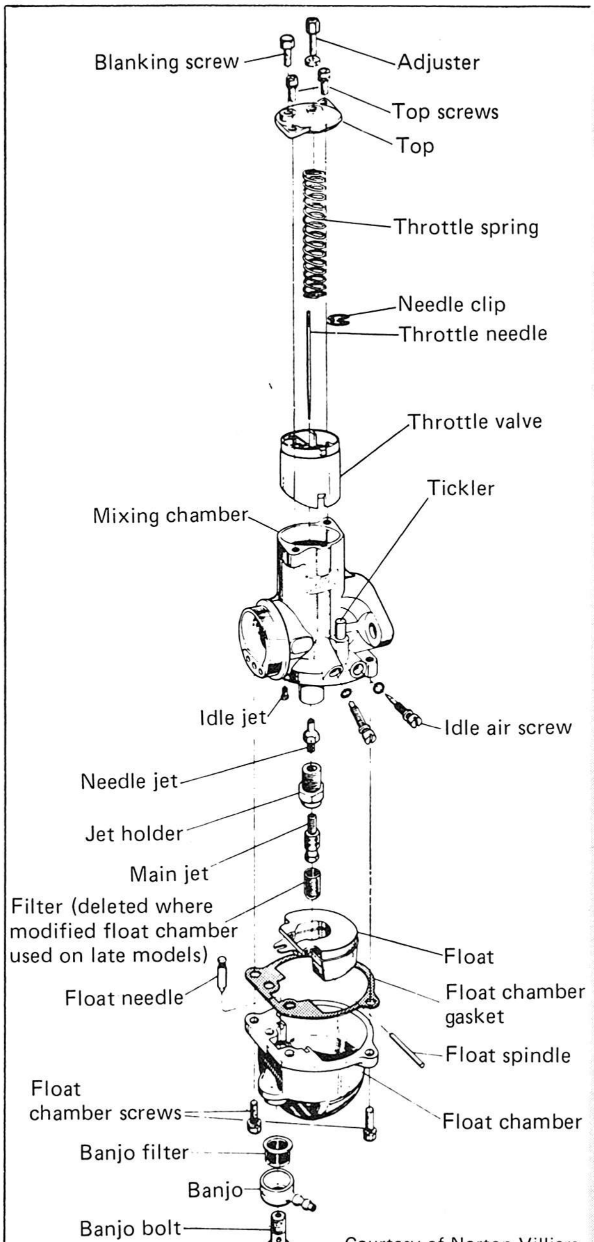
There are other factors. The vaporization of excess droplets of fuel tends to cool down the entire combustion volume, reducing the effective pressure. The fuel vapor exerts part of the total pressure in the cylinder, during induction, reducing the pressure which the air can attain, and thus the weight of air in the cylinder. The companion effect of too much fuel is too little air, caused by the presence of the fuel vapor.

The net effect is that power is reduced when the mixture is made rich, assuming the richness is well above the maximum-power ratio.

The important information in the fish-hook curve, however, is the shape of the curve itself. Notice that the power falls off less severely as the mixture becomes rich, compared to the drop-off as the F/A ratio becomes lean. If you can't get the exact maximum-power setting, you are better off rich. For this and other reasons.

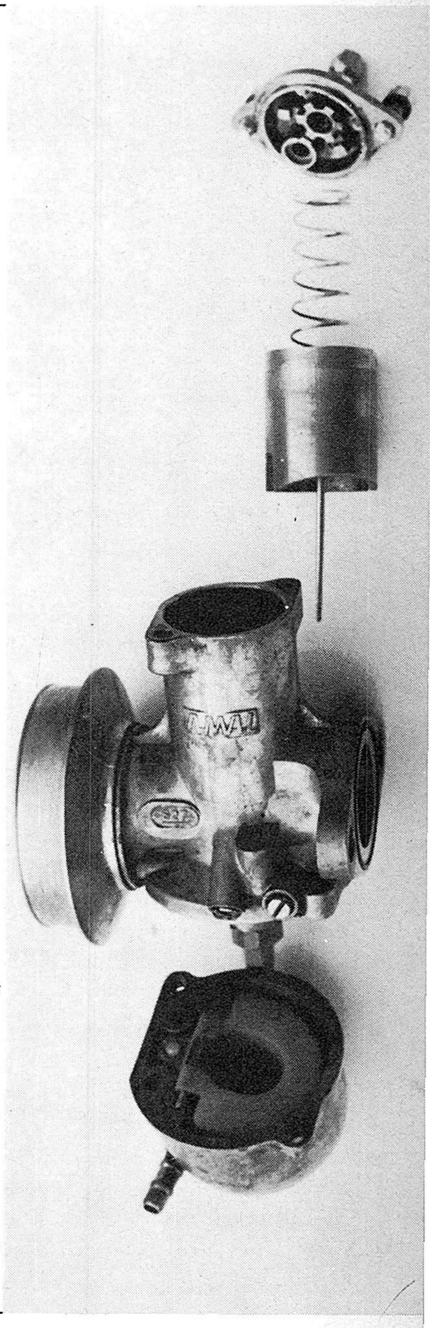
Major internal cooling of an engine results from evaporation of the fuel droplets which emerge into the air stream flowing through the carburetor. Thus, the F/A ratio has a direct bearing on engine temperature. Engine temperature, in turn, is an indication of F/A ratio. Which is why you can, sometimes, look at a spark plug and tell if the F/A ratio is about right.

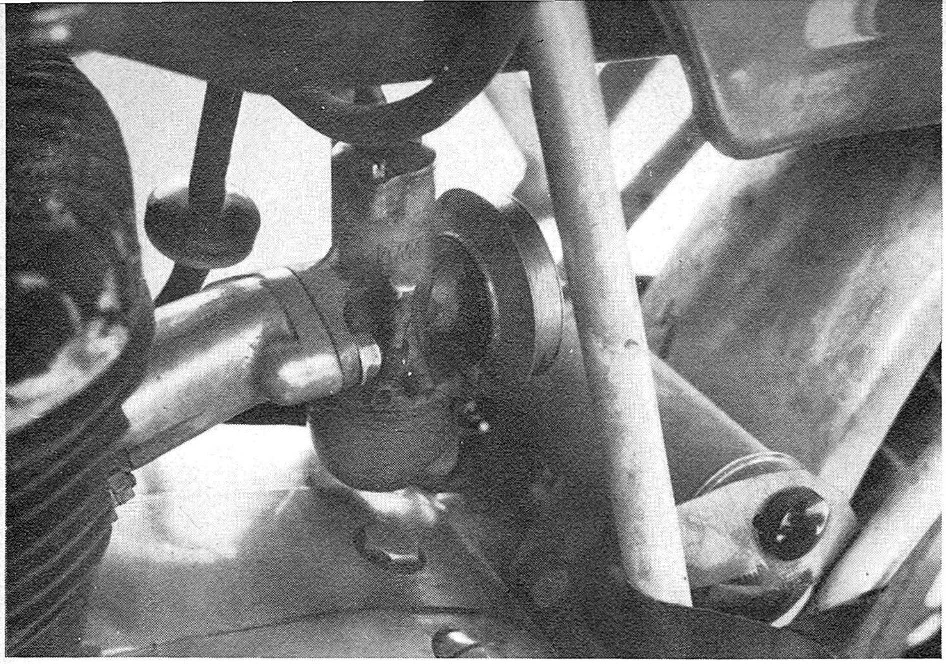
The Inner AMAL



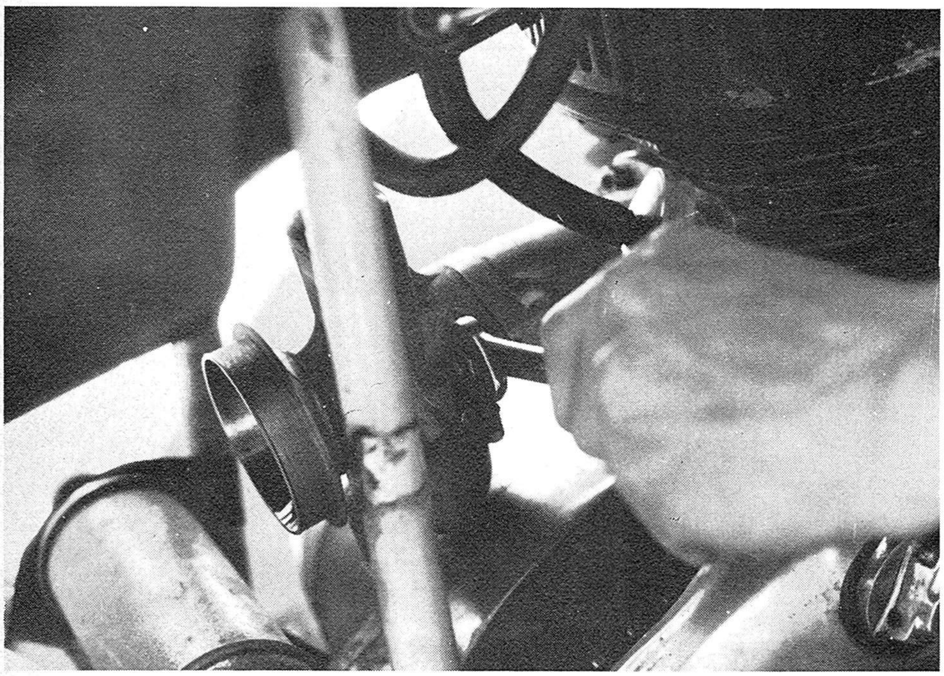
Courtesy of Norton-Villiers.

AMAL CONCENTRIC FLOAT CARBURETOR

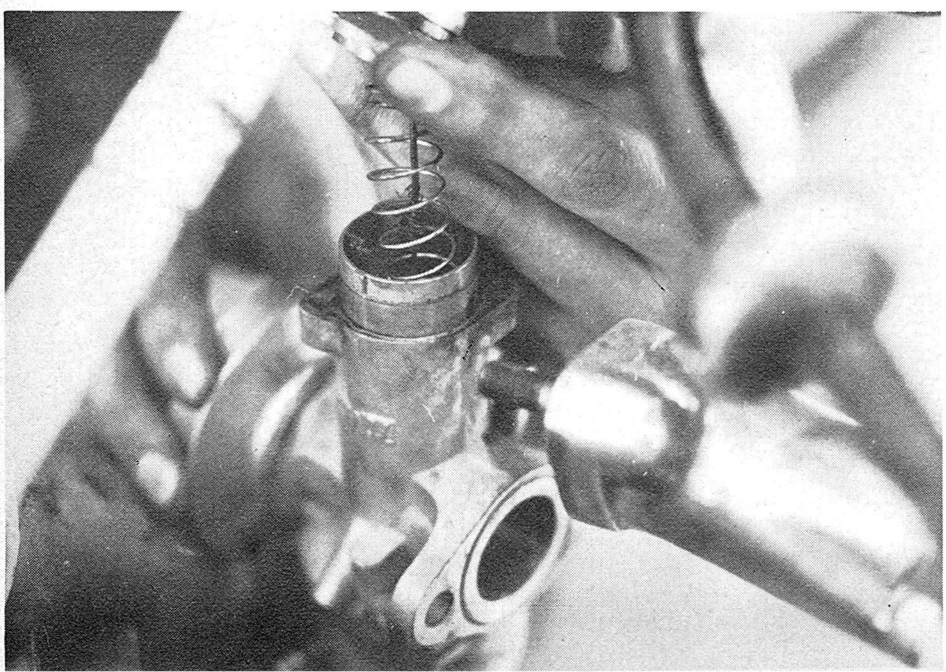




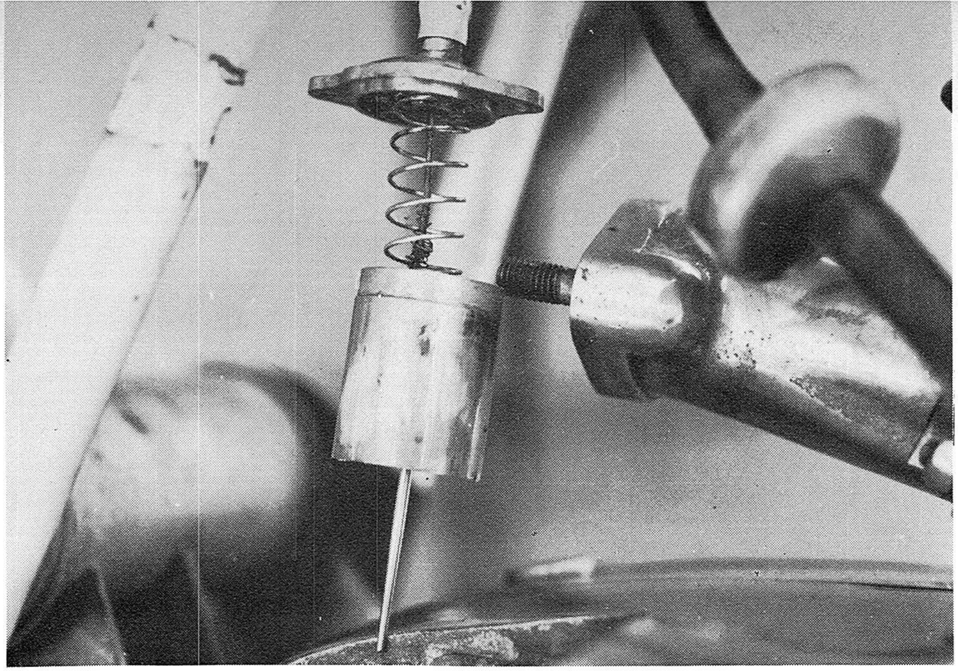
This carburetor lives in such close quarters that it is necessary to remove it from the bike in order to get either the top or the bottom off. It's a trials bike, as you can tell from the length of the inlet pipe between carb and engine. Long tracts tune the inlet at low RPM. Race bikes have very short inlet systems. Air cleaner has already been removed.



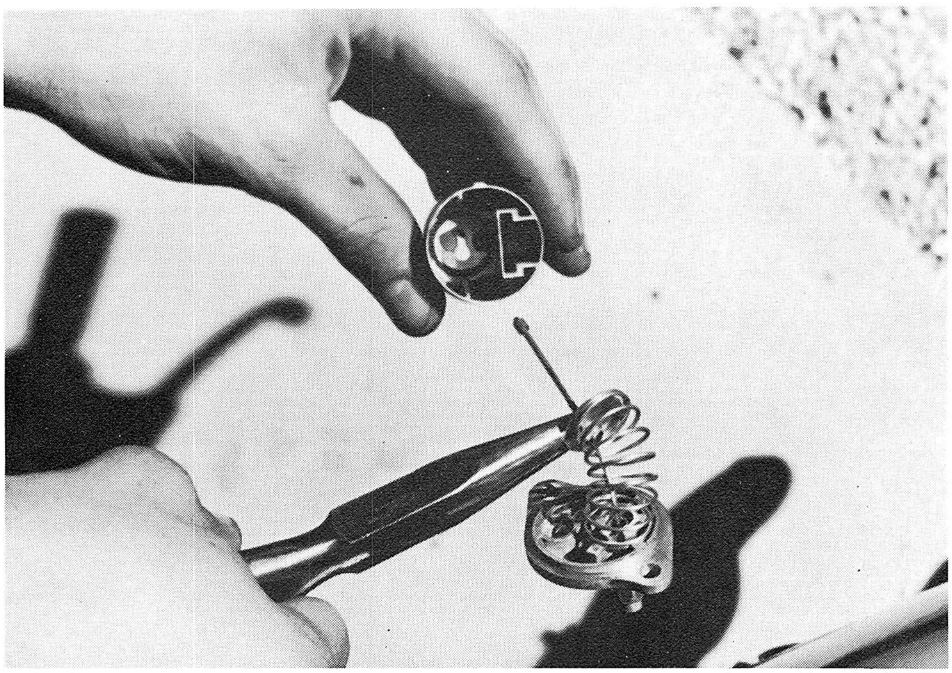
Nuts holding carburetor flange to flange on inlet pipe are removed. Fuel line is black neoprene tubing with in-line fuel filter, and fuel line has already been removed from fitting at bottom of float bowl (not visible). Other fuel line is crossover between the two sides of the tank.



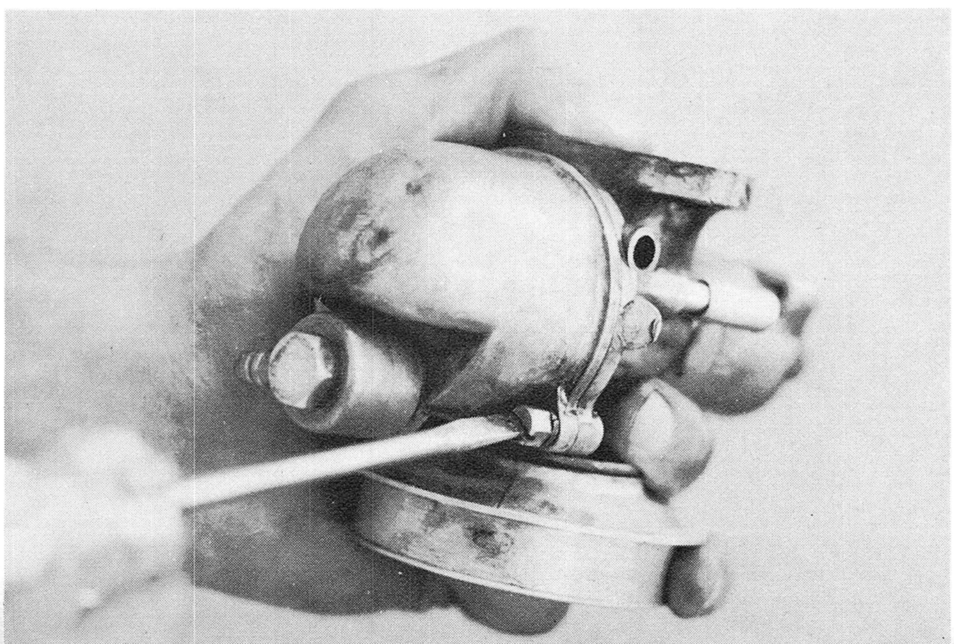
Carb is pulled off mounting studs, tilted to allow top screws to be removed and cap pushed up. This pulls on throttle wire and pulls slide out the top. The thing that's wrong in this photo is more apparent in the next.



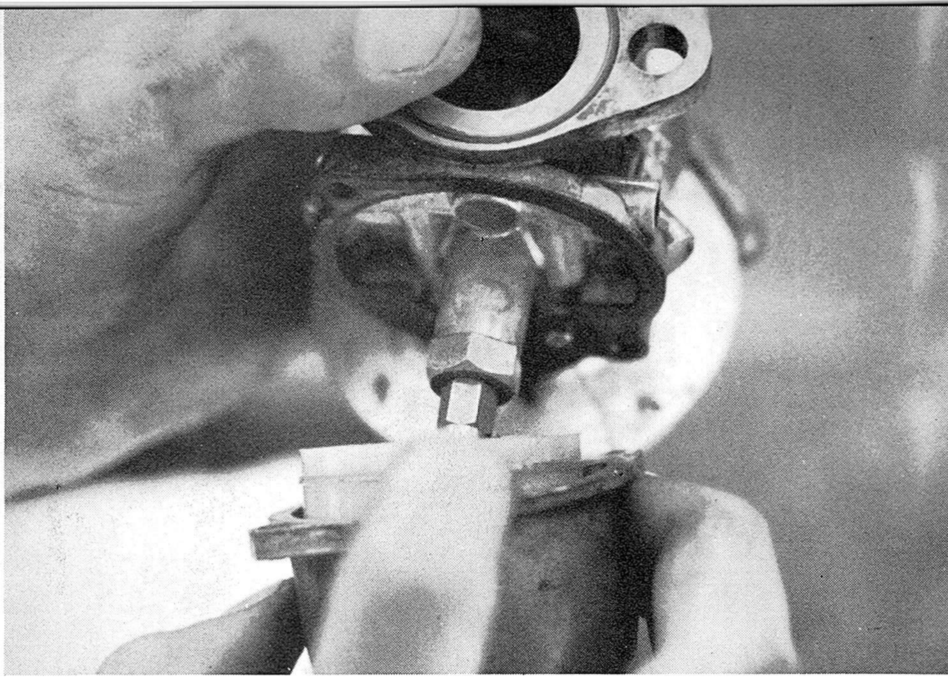
Throttle slide now fully removed from carb with needle still in place. What's wrong is throttle cable is frayed. Notice loose strands near top of throttle slide. Time to replace this one. Also, notice scuff marks and wear pattern on back side of throttle slide. Eventually this wear will allow air leak into carb when throttle is closed, causing lean mixture at idle. When wear is advanced, air pulses through carb will make the slide rattle.



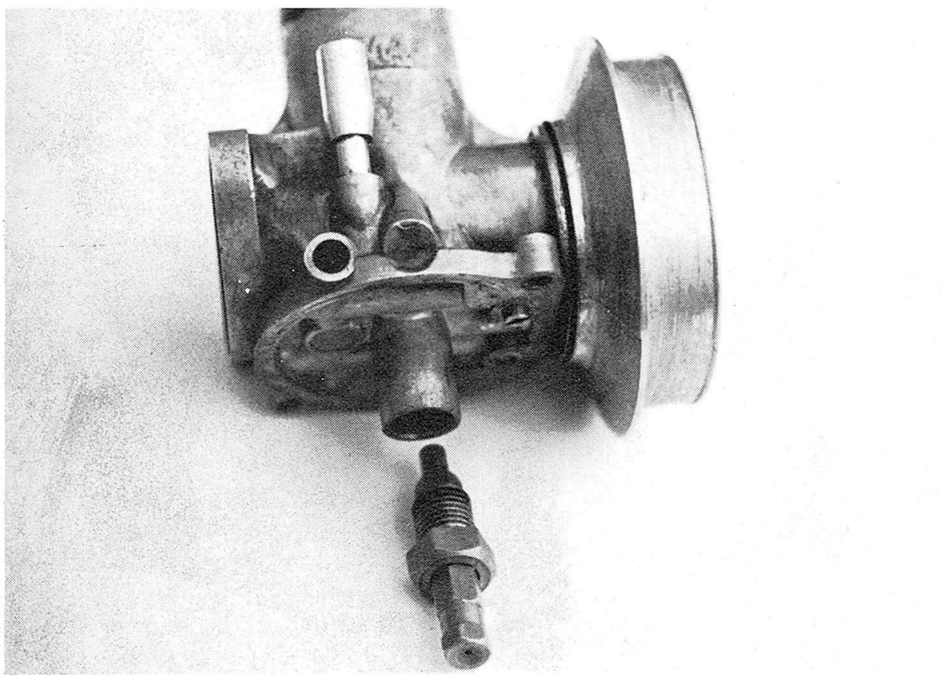
With fingers or longnose pliers, throttle cable is removed from slide. Disc between spring and pliers fits down in bottom, on top of needle clip. Groove in disc embraces top end of needle. You can only get this disc to fit in one way, but you can try other ways for a very long time. Watch how it comes apart and you'll know how it goes together.



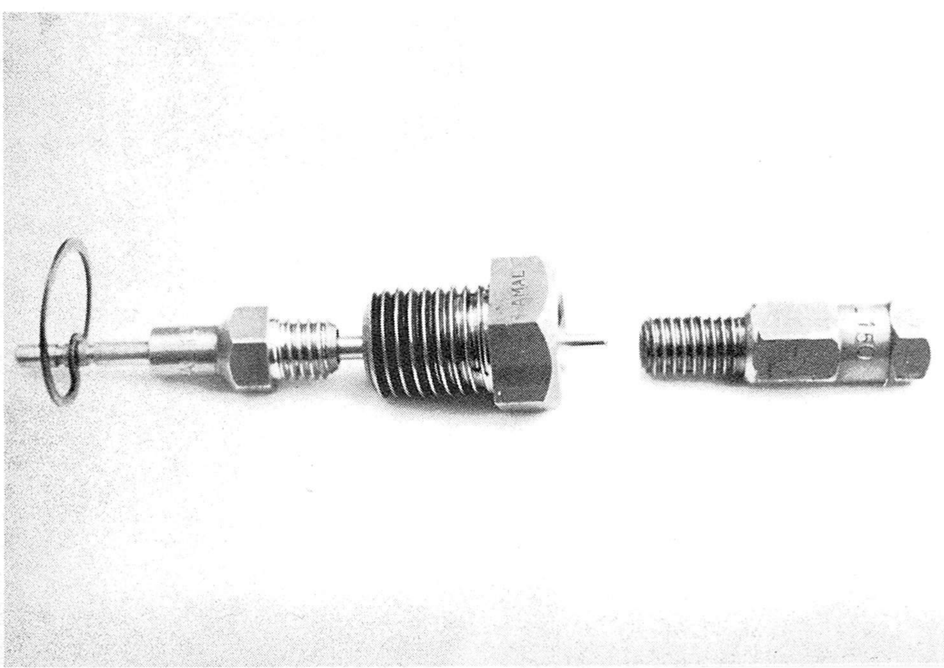
Screws holding float bowl are removed. Gasoline will come out of bowl while doing this, so be careful not to do it next to your furnace or hot water heater. "Banjo" fitting on the bottom of the float bowl is where the fuel line connects.



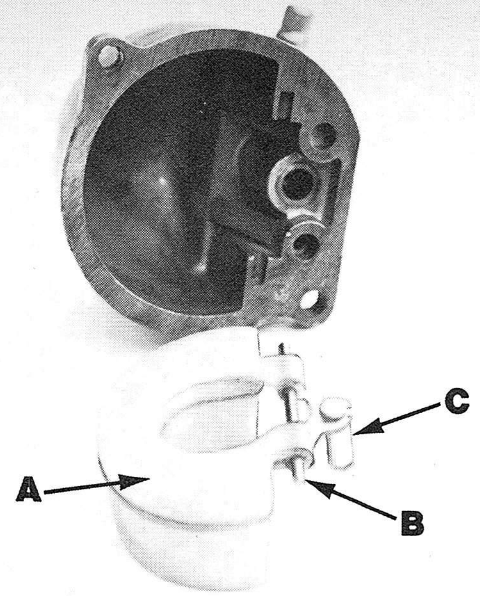
Float bowl comes off disclosing main jet holder, idle jet in background, gasket between bowl and carburetor, and "O" ring which provides seal between carb flange and inlet pipe flange. Index finger is holding float in place so it doesn't fall out along with associated parts.



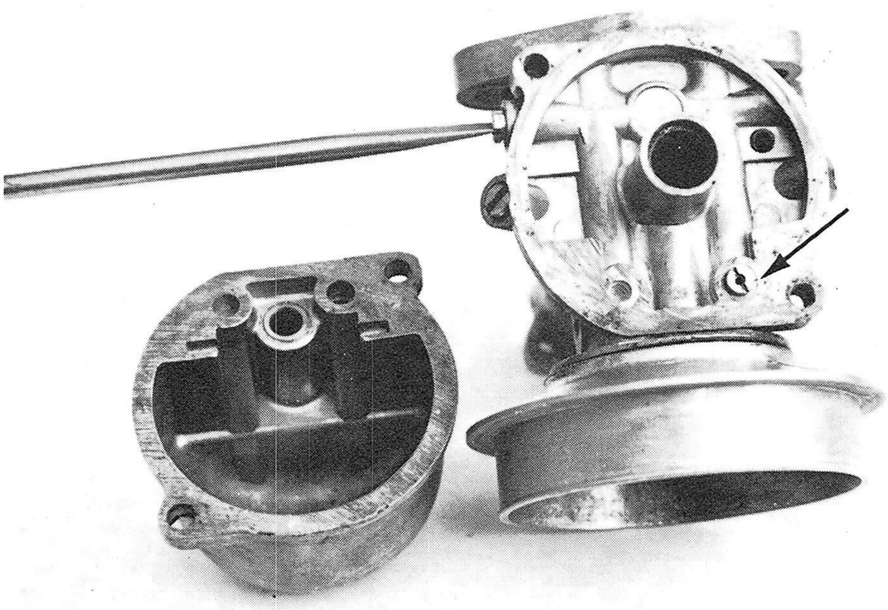
Jet holder is unscrewed, carrying with it both the main jet (at the bottom) and the needle jet. Plunger on side of carb body is "tickler." When depressed, it extends downward into float chamber, holding float down so excess gas can enter bowl and enrich mixture for starting. Air horn, on inlet side of carb, also unscrews and can be changed for different size.



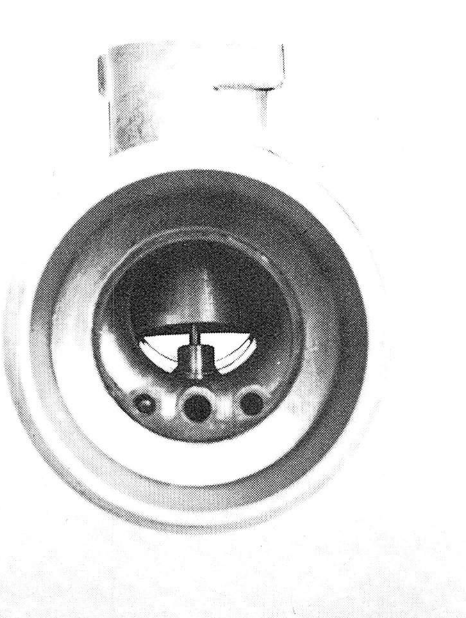
Main jet and needle jet are unscrewed from jet holder. Needle (with clip) is inserted to show how it works when it's all put together. Note size numbers stamped on jets. Main jet is a 150.



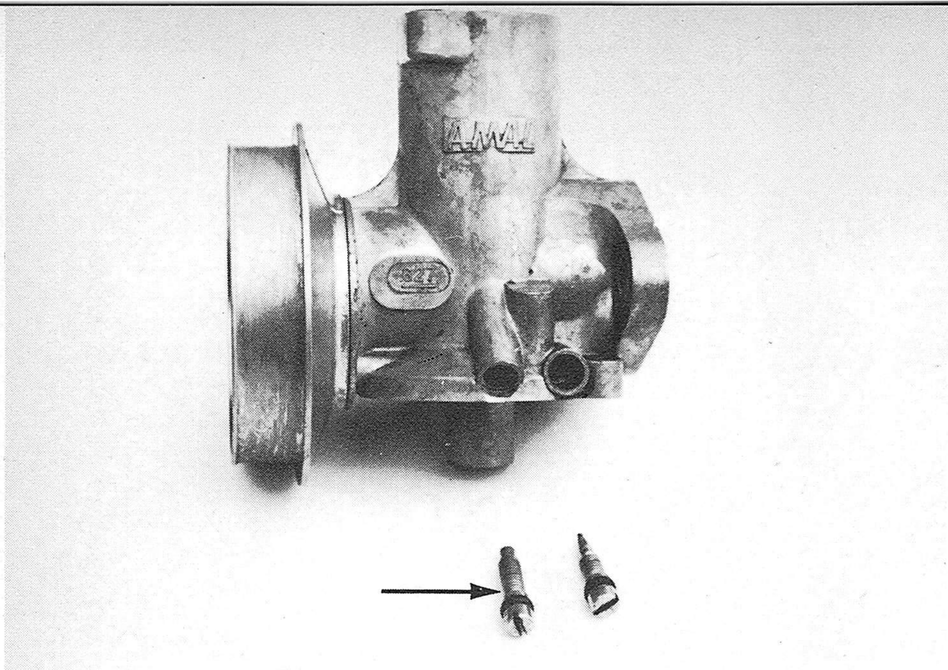
Float A, float pivot pin B, and float needle C are removed from bowl. Needle merely hangs in yoke on float and will fall out anytime you're not looking. Pivot pin slides out endways and is also easy to lose. In use, pivot pin fits into groove in bowl. Needle drops down into hole where it seats against a taper. When float rises, needle shuts off fuel. Float level is not adjustable on this carb.



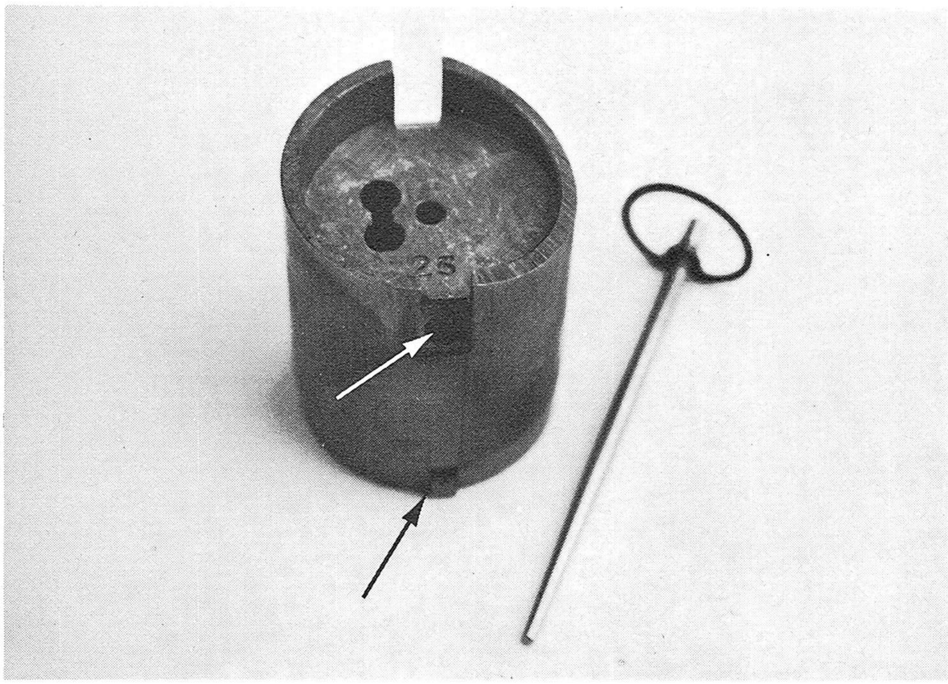
Pilot jet (idle jet) is in bottom surface of main carb body, indicated by arrow. When bowl and body are assembled, jet fits into top of drilled passage extending down to bottom of bowl. Fuel flows up through passage, through jet, and along tunnel in carb body, making left turn to get to round plug near top of picture. Underneath this plug is the pilot outlet into the bore of the carb.
Idle air enters through a hole on the front of the carb and travels through the tunnel on the left side in the picture. The idle air screw adjusts flow through this passage and is shown being adjusted with a screwdriver. Throttle stop screw is visible next to the idle air screw. Bleed air passage runs right down center of carb between the two tunnels used for the idle system. These carbs are made left and right, so some things are duplicated. What is not needed is plugged up, or not drilled out.



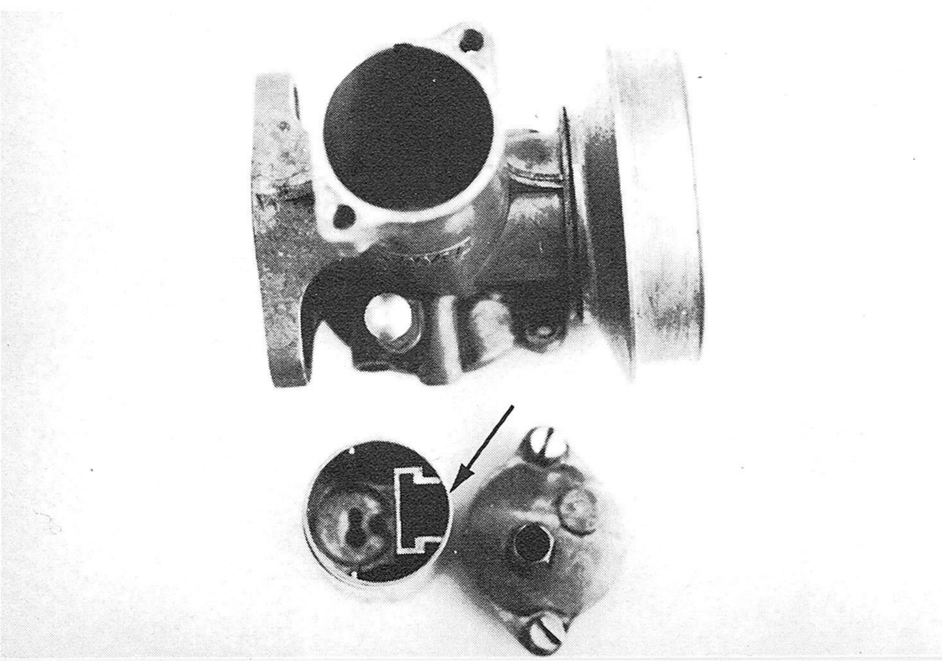
Plugged-up hole on left would be open if this were a carb for the opposite side, and the hole on the right would be plugged up. As it is, the open hole on the right is the entry for idle air. Center hole runs straight to nozzle and provides passage for bleed air. Throttle slide and needle have been put back in to show part-throttle setting.



Throttle stop screw (arrow) fits into bore which is inclined upwards and has blunt end. It stops throttle slide from closing completely and is used to set idle speed. Needle-pointed screw is idle air screw. Tapered tip works in idle air passage to regulate flow. "O" rings provide friction to keep screws from vibrating out.



Just below stamped number (25), in groove on the side of the slide, you can see where the throttle stop screw engages the slide (white arrow). Needle passes through the hole in the center of the slide. Control cable is installed by passing it down through one of the two holes which look like a figure eight, and then back up into the other hole which makes a pocket to hold the fitting. On far end of slide, notice key sticking out (black arrow). This fits in groove in carb body and keeps slide from rotating.



Top view. Rectangular cavity in throttle slide (arrow) is for an "air slide" when used. This is a "choke" which drops down into the bore of the carb and is used for starting enrichment. Control is by an "air lever" on the handlebar of bikes so equipped. Boss on cap would be drilled for control cable if this carburetor used the air slide. It has a tickler instead. Notice that the hole for the throttle-control cable is off-center. The screw holes are symmetrical and the cap can be put on the wrong way if you try hard.

Now, sir, what was it that you wanted to change in this carburetor?

Getting The Air In

Getting the air into the engine is a fairly simple process.

As the piston in the cylinder moves, it acts as a pump, creating a reduced pressure. When the inlet system is open, air flows through the carburetor and into the engine, motivated by the inside-outside pressure difference.

If there is enough time allowed, air will flow into the engine until the inside-outside pressure difference is zero. Then, it will stop flowing, and the pressure inside the engine will be the same as the outside barometric pressure.

As engine speed increases, two things happen which affect the pressure and density of the charge.

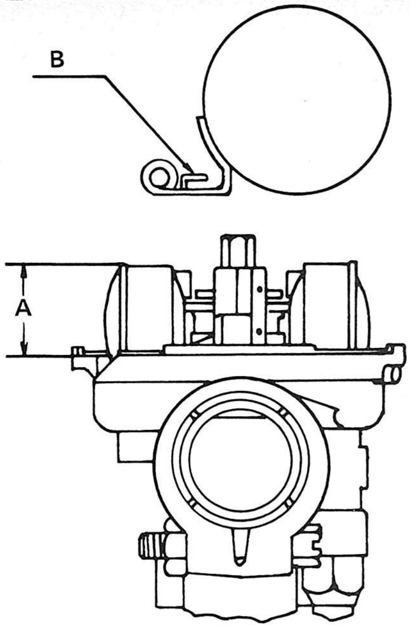
Because of increased RPM, the time allowed for each intake event becomes shorter, allowing less air to flow in.

As RPM increases, particularly with open throttle, the inertia of the moving columns of mixture or exhaust begins to have an effect. On the inlet side, once the flow of air has started, it will tend to continue even after the pressure-differential becomes zero. If the inlet port or valve is left open, this "ram" effect can pack more mixture into the engine. If the inlet system is closed at exactly the right instant, the air pressure in the engine can exceed outside air pressure, due to the ram effect.

A similar thing happens in the exhaust system. If the exhaust valve or port is left open, the outrushing gases in the pipe will tend to extract more of the exhaust products from the combustion chamber.

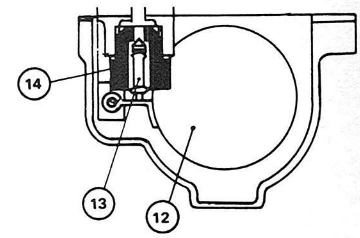
Both of these ram effects may be enhanced by acoustical tuning of inlet and exhaust, taking advantage of sound pressure-waves along with the inertial effects.

When ram or tuning is most effective, the engine passes through its torque peak. At higher speeds, breathing becomes less efficient, due to shorter time intervals and to the fact that tuned inlet and exhaust systems work only over a limited range of RPM.



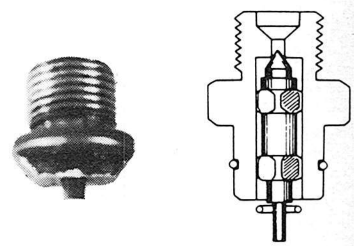
FLOAT LEVEL ADJUSTMENT

Level of fuel in float bowl is important. Some carburetors have an adjustment. Tang B on float is bent up or down as needed. With carb held upside down, weight of float forces needle fully against its seat in the fuel valve. Tang B is then adjusted for proper measurement A.



FLOAT MECHANISM

Cross section—Float and valve
12 – Float
13 – Needle
14 – Needle seat



NEEDLE AND SEAT ASSEMBLY

Needle and seat assembly in which needle is captive in seat. Entire assembly is replaced when it leaks.

The amount of air or mixture which gets into the engine during each intake event is measured by a factor called *volumetric efficiency*. The idea is that, if the cylinder got completely "full," efficiency would be 100%. "Full" means the same density as outside air.

Because cylinders don't get full at high speeds, volumetric efficiency can get down to values like 30% or 40% and, in best conditions rarely exceeds 80% or 90% at the peak of torque.

Volumetric efficiency is not a good name for this. The cylinder al-

ways has the same volume for any position of the piston, no matter how fast it is running. Whatever amount of air gets in will fill it up.

What we are really concerned with is the weight of air inducted, so this factor should properly be called "weight efficiency," "induction efficiency," or something like that.

The total weight of air drawn in depends on both the density of the outside air and the volumetric efficiency of the engine.

GETTING THE FUEL IN

Causing the gasoline to join into the air flow is not so simple in concept. However, it is interesting and fundamentally is what carburetors and carburetor tuning are all about. To get air into the engine, all you need is a hole. To get a fuel-air mixture, you need a relatively complicated mixing system which makes use of a venturi.

Everybody knows that a venturi is a tube with some obstruction or reduced diameter in it. When air is flowing through a venturi, there is a pressure reduction at the restriction. The reduced pressure is used to pull gasoline out of the carburetor float bowl, into the air stream.

VENTURI BASICS

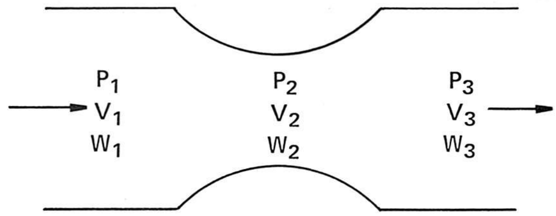
We are often asked to accept the above on faith which, like many other acts of faith, then requires us to accept a lot more things on faith. Such as the list of rules about carburetors given above. It is nearly as easy to find reasons.

If you accept the idea that energy can exist in different forms, and can change back and forth between them, then you will see that that's what happens in a venturi.

In the sketch above, air enters and has pressure, velocity and weight, denoted by P_1, V_1, and W_1.

Temporarily, we will assume that those quantities have the same values at the exit. $P_1 = P_3$, etc. Which means we are ignoring the friction losses caused by the air rubbing on the sides of the air passage. These losses cause a reduction in pressure at the exit of a venturi or carburetor, however that is not related to the venturi action, and we can set it aside for now.

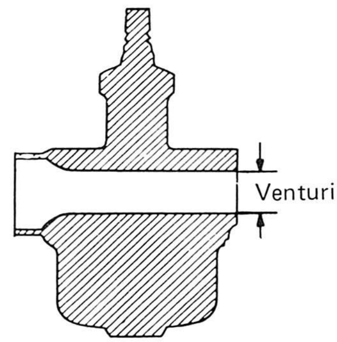
If some weight of air goes in at some velocity, and the same weight of air comes



BASIC VENTURI

When some weight of fuel-air mixture flows through a venturi, energy is exchanged between pressure and velocity but the total energy remains constant. At the venturi restriction, velocity goes up, pressure goes down.

A venturi is *any* restriction or reduction in size of a passage carrying fluid. When the fluid, such as fuel-air mixture, gets to the restriction it has to speed up. Typically venturi restrictions are streamlined to reduce turbulence and friction losses against the sides of the passage. It is not necessary to enlarge the passage again, after the restriction, in order to have venturi action. Some designs keep the passage small and the velocity high all the way from carb to engine.



VENTURI SIZE

Feeler gages measure point-gap, valve clearances, and are generally useful.

out at the same velocity, then as the air passed through the restriction in the venturi, it had to speed up. In order for the same amount of air to squeeze through a smaller passage, it must speed up.

Therefore, V_2 (at the restriction) is higher than V_1. W_2 is the same as W_1, and the question is, what happens to the pressure?

To speed up through the venturi, the air must have received some energy from somewhere. When the air slows down again, after the venturi, it will return that energy to wherever it borrowed it.

The "energy bank" in this case is the *pressure of the air.* In order for air to have pressure, it must have been compressed by something. Therefore, work was done on it and it contains potential energy.

PRESSURE ENERGY

An example of energy in the form of pressure is liquid in a container, with a spigot at the bottom.

We are going to consider the energy stored in a thin layer of the liquid at the top of the tank, which is some distance, h, above the spigot.

This layer has a mass, m, and because it is in the earth's gravity it exerts a downward force which we call weight. The mass of an object multiplied by the value of gravity, g, (32.2) yields the weight or downward force. The potential energy stored in the layer at the top is:

$$PE = mgh .$$

This is equivalent to saying that we lifted a weight of liquid, (mg) upwards by a distance (h), and the work-energy to do that is now stored.

If we open the spigot and allow liquid to flow out until the layer, m, is gone, then the potential energy of that layer no longer exists. It has changed from PE into kinetic energy of the flowing stream coming out of the spigot.

The kinetic energy contained in a body in motion is

$$KE = 1/2\ m\ v^2$$

where m is mass and v is velocity.

The trick is to recognize that the mass of liquid which left the top of the tank is the same as the mass flowing out of the spigot, and the energy was simply transformed from PE to KE. Therefore,

$$PE = KE$$

or

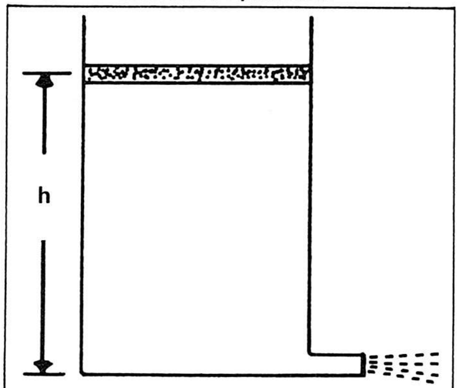
$$mgh = 1/2\ m\ v^2 .$$

Canceling m on each side, and then solving for v,

$$v = \sqrt{2gh} .$$

Which tells us that the velocity of liquid flowing through a spigot (or jet) is determined only by the height of liquid above the spigot, and that the velocity is proportional to the square root of that height.

This drawing illustrates that the pressure of a liquid is governed by the height, or head, of liquid above the discharge orifice. Pressure anywhere in a system can be stated in terms of the head of liquid which would cause that amount of pressure.



HEAD OF LIQUID

PRESSURE AND HEAD

It should be apparent that the pressure at the spigot is determined by the weight of the column of liquid above it. For any particular density of liquid, the weight of a column is determined by the height of the column. Therefore, the pressure in a system can be indicated by stating the height of a column of liquid, which produces that pressure, rather than stating the actual pressure in pounds per square inch.

When so used, the height is referred to as the *head* and the only other information required is the liquid being used or implied. Common use of the word "head" refers to heads of water, gasoline, or mercury, and the heads are often stated in inches.

If the distance from the center of your fuel tank down to the inlet of your carburetor is 18 inches, then the average head of gasoline is 18 inches, and that is what causes flow into the float chamber of the carb.

When the float valve is open, the *velocity* of fuel flow is:

$$v = \sqrt{2gh} .$$

The *volume*, in a given time, will be proportional to the area of the hole, and the *weight* will be proportional to both volume and the density of the liquid.

FUEL FLOW THROUGH A JET

The equation for weight of fuel flow, through a jet, is then

$$W_f \sim A \sqrt{hD}$$

where W_f is weight of fuel flowing in a given time, A is the area (not diameter) of the opening in the jet, h is the head or pressure, and D is the density of the fuel.

This equation is usually modified to add a correction factor which expresses how well the jet is shaped, or streamlined, to assist fuel flow.

We started out considering the change from PE to KE when some pressure causes a liquid to flow through an orifice. Through a stroke of very good luck, we wound up discovering the rules for fuel flow through a jet.

The main purpose of the excursion into PE and KE, however, was to show that these two forms of energy can change back and forth in a venturi. So, let's get back to that.

VENTURI EQUATION

Referring again to the sketch of a venturi, we can now get a better idea of what is going on. At the entrance to the passage, there is some total energy, part PE and part KE. At the restriction, velocity increases. The total energy does not change. As KE goes up, PE goes down the same amount. After the restriction, PE and KE

can return to the original values, neglecting friction losses.

A simplifying assumption which we will make, also temporarily, is to assume that the fluid going through the venturi is not compressible (or expandable) and therefore does not expand when it enters the reduced-pressure region of the venturi. This is considered true for gasoline but not true for air. So, later on, we will have to consider the compressibility of air.

For an incompressible fluid in the venturi, we can say: The total energy of the fluid stream going in is the same as the total energy of the stream going out and therefore is the same as the total energy of the stream as it passes through the restriction.

The matter of interest is the idea that the total energy at the inlet and the restriction are the same and that the energy at each point is composed partly of KE and partly of PE. Therefore

$$PE_1 + KE_1 = PE_2 + KE_2$$

or,

$$mgh_1 + 1/2\, m(v_1)^2 = mgh_2 + 1/2\, m(v_2)^2$$

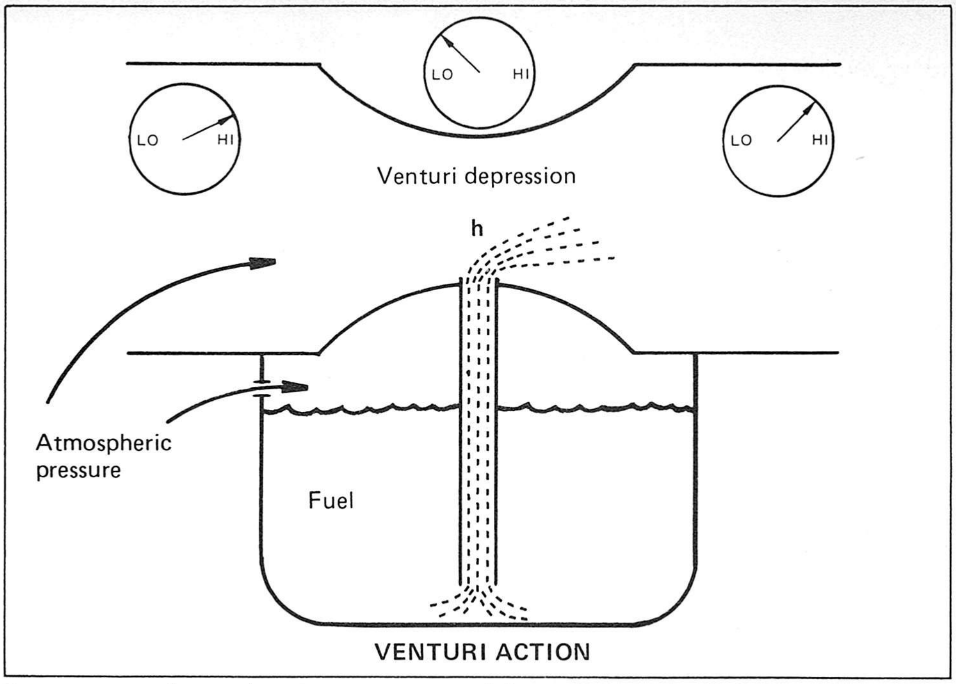
What this elegant arithmetic is trying to conceal from us is the basic idea that when the fluid speeds up, the pressure goes down.

By manipulating this equation and introducing the density of the fluid, we can arrive at an equation for the weight of fluid flowing through a venturi, when the fluid is incompressible.

The result is:

$$W \sim A\sqrt{hD}$$

If this looks familiar, it is exactly the same expression as we got earlier for fuel flow through a jet. As long as the fluid is incompressible, this equation works fine.



Pressure gages show reduced pressure—venturi depression—at restriction in carburetor. Fuel bowl is at atmospheric pressure. Pressure difference causes fuel to flow into air passage of carb.

VENTURI DEPRESSION

It is useful, about now, to stand back from the arithmetic and consider what is really happening. The arithmetic, hopefully, was an intellectual convincer or pacifier for those who need that sort of thing.

The arithmetic said that the pressure will drop in a venturi due to increased velocity of flow. This reduction in pressure is often referred to as the *venturi depression* and the symbol for it is h.

In a carburetor, the venturi depression does not *cause* air flow. It is the *result* of air flowing through the carburetor due to the pumping action of the engine.

The venturi depression does cause fuel to flow out of the float bowl and to merge with the air stream through the carburetor. With more air flow, there should be more fuel flow, consequently the venturi depression is sometimes considered to be a signal which tells the fuel supply how much is desired and when. The word *signal* in carburetor literature means venturi depression. Sometimes venturi depression is also referred to as *vacuum.* Anyway, now you know most of its names.

If we add a float bowl to a venturi, we can see the effect of the venturi depression on fuel flow. A float operates a needle valve and tends to keep the fuel level constant in exactly the same way that the water level is maintained in the water tank of a toilet.

The fuel level is maintained some distance below the place where fuel flow enters the air stream.

The point of interest is that the venturi depression h is the measure of air flow and the cause of fuel flow. The value of h is the same in respect to the air flow or in respect to the fuel flow.

The pressure difference, causing fuel to flow, is the difference between the pressure in the float bowl and the pressure h in the venturi. Usually, the pressure in the float chamber is the same as outside air pressure because the bowl is vented to the outside.

FUEL-AIR RATIO

The F/A ratio is the weight of fuel divided by the weight of air that flows into an engine over an interval of time. This can be expressed by writing an equation for each and dividing them.

$$\frac{W_f}{W_a} \sim \frac{A_j\sqrt{hD_f}}{A_v\sqrt{hD_a}}$$

where W_f and W_a are weights of fuel and air respectively, A_j is the area of the fuel jet, A_v is the area of the venturi passage in

the carburetor, D_f and D_a are the densities of the fuel and air, and h is the head or venturi depression.

If there was a perfect carburetor, this equation would describe it. And, if there was an ideal engine, a perfect carb would satisfy its needs.

In the equation, on the right side, assume nothing changes except h. Then, some change in air flow will generate a different value of h and that will produce a change in fuel flow such that the F/A ratio is constant because h appears in both numerator and denominator of the fraction.

In general this is not true since fixed-venturi carburetors are known to provide richer mixtures as air flow increases. The equation is valid for some fixed amount of air flow and it is nearly valid when the air flow changes only a small amount.

MIXTURE ENRICHMENT

The reason the equation above does not hold over large air flow changes is the one I have been warning you about—the fact that air is *compressible*, or *expandable.* When air passes through a venturi and encounters the low-pressure area, it immediately expands.

This is equivalent to suddenly making more air, and the air velocity will increase, causing a still greater venturi depression.

The result is that h is not a linear function of air flow. In a simple fixed-venturi carburetor, the head rises rapidly with increased air velocity, pulls too much gasoline into the air stream, and causes a richer mixture at higher air-flow rates.

We treat this aspect of the problem only in concept because the arithmetic is complicated. You can find it in engineering-level books and see that it contains difficult things like exponents which are not integers.

All we really need to know is that simple carburetors will not provide a constant F/A ratio and then take a look at what is done to correct the problem.

THE FIX

If the area of a venturi were made larger and smaller as air flow changed, it would be possible to maintain a constant venturi depression. The manually-operated throttle-slide of a motorcycle carburetor tends to do that because it is raised up to allow more air flow, and moved down to reduce air flow.

When the throttle slide is pulled up, it not only allows more air to flow through, but also opens up the venturi restriction, tending to cause a constant pressure drop in the venturi throat.

Assume that the throttle-slide is controlled in such a way that the pressure drop actually is constant over a range of air-flow rates. The fuel flow responds to the pressure drop and it, therefore, would not change. Because the fuel flow must change with air flow, a metering valve in the fuel system is necessary.

This is accomplished by the tapered needle, working in the needle jet. As the throttle-slide moves up and down, the needle changes the effective area of the needle jet.

A carb which changes the area of its venturi is called, not surprisingly, a *variable-venturi* carburetor. Most motorcycles use this type.

In this type of carburetor, the *signal* which governs fuel flow is not the venturi depression because theoretically that doesn't change. What does change in accordance with air flow is the position of the throttle slide. This moves the needle up and down and controls the flow of fuel through the needle jet.

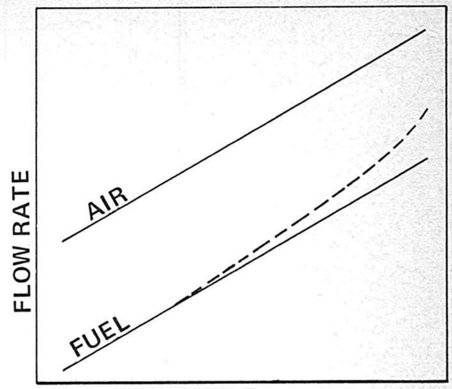
The main benefit of this arrangement is that it cancels out the effect of air compressibility. Over the control-range of the needle, the F/A ratio is determined by the taper of the needle and the size of the jet which surrounds it. The designer can control F/A ratio as he chooses by grinding a different taper on the needle. The tuner can adjust the F/A ratio by positioning the needle higher or lower or in extreme cases by using a different needle and/or needle jet.

As you remember, at small throttle openings and at full throttle openings, the needle is not the principal regulator. At idle, we use a different system to set mixture. At open throttle, when air flow increases without a corresponding increase in venturi area, the mixture will become rich.

However, for small changes in air flow (50% rather than 1,000%) the enrichment is small and, at full throttle, we want some anyway.

A refinement of the variable-venturi carburetor, called a *constant-vacuum* carburetor, positions the slide automatically. The CV carb is discussed in a following section.

Without the automatic feature, the rider is expected to position the throttle slide reasonably in accordance with air flow. If he doesn't do this, problems result, one of which is called "loading up."



FUEL-AIR RATIO VARIES WITH FLOW RATE THROUGH VENTURI

Solid lines show fuel flow increasing in a linear way with an increase in air flow, which would result if both fuel and air were incompressible fluids.
Dotted line shows real-world increase in fuel flow as air velocity increases (due to compressibility of air).
Some discussions of this non-linear relationship seem to regard it as a flaw in nature's design of the venturi, which is not necessarily so. If a carburetor did flow air and fuel as shown by the solid lines, we would have to modify it so as to get higher fuel delivery with open throttle because we want the mixture to be rich when maximum power is being delivered.

ON THE MOUNTAIN

Increased altitude affects air density but does not appreciably change the density of gasoline.

The F/A ratio equation applies, with reservations, if we assume some fixed throttle opening and

look to see the effect of a change in D_a.

$$\frac{F}{A} \sim \frac{A_j \sqrt{h\,D_f}}{A_v \sqrt{h\,D_a}}$$

If D_a (density of the air) changes, then the denominator of the fraction changes by the square root of the change in D_a. If the F/A ratio is not to change as a result, then the numerator, on the right side, must change the same amount as the denominator changed, in order for the value of the fraction to remain constant.

In the numerator, the change is made to A_j, the area of the jet.

In an actual carburetor, the correction at full throttle would be the size of the main jet. The correction at mid-throttle would be needle position, and at idle it would be the setting of the air adjustment or the idle jet.

We noted a reservation in respect to use of this equation to calculate jet changes when density changes. The equation does describe changes due to variations in outside air density, however the reservation is that it still does not take into account changes due to the compressibility of air.

At higher altitudes, in order to induct any particular weight of air, a greater volume of air must be taken in. This leads to increased velocity in the venturi, a higher venturi depression, corresponding non-linear expansion of the air in the venturi, and an unduly rich mixture.

If the equation above is used to calculate jet changes, the change indicated will be smaller than the change required in the real world.

We therefore use a rule of thumb which gets in the ball park, and then test for the proper size to use.

- **Factory jetting is normally suitable for altitudes up to about 3,000 feet.**
- **Between 3,000 and 6,000 feet, main jet size should be reduced about 5%.**
- **For each 3,000 feet above 6,000, reduce main-jet size an additional 4%.**
- **After the main jet is changed, needle and idle settings are determined by testing and/or plug readings.**

Geoff Binks, of AMAL Ltd., has been helpful in providing data and illustrations used in this book. In a letter Mr. Binks advises:

The percentage reductions work quite well, but further experimentation may be necessary to correct the carburetion completely. You will of course appreciate that jetting down will only correct the carburetion and will not restore the power loss which will be inevitable.

To illustrate the problem, assume a bike is tuned for sea level and then moved to 7,000 feet.

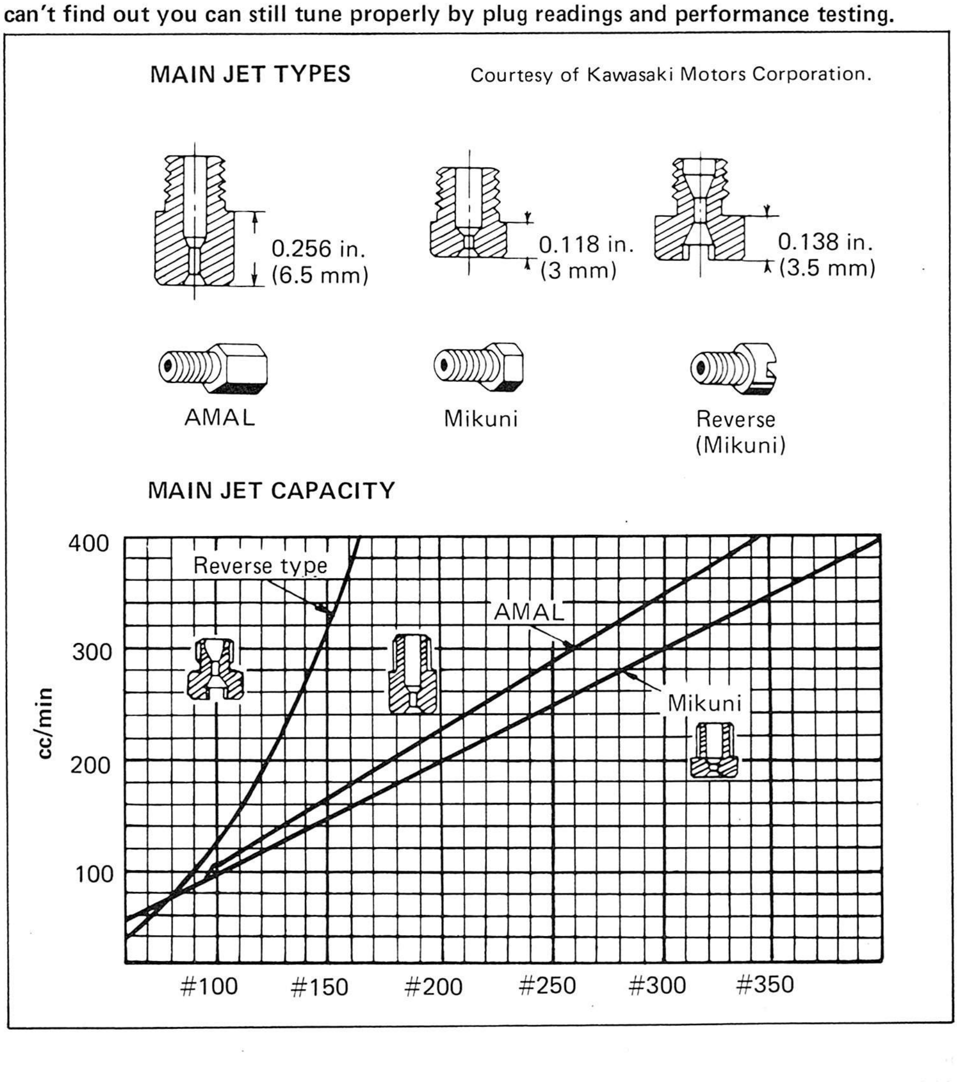
Some tuners remember that air density changes about 3% for each thousand feet of altitude and reason that the oxygen content of a given volume of air would be 21% less at 7,000 feet. This is correct. They further reason that fuel flow should be reduced by 21%, also correct. Then, they decide that the main jet area or flow rate must be reduced by that amount. Wrong, because it fails to take into account the fact that the carburetor responds to the square root of density.

The mathematician looks at the F/A equation, notes the square-root business and says, "Aha, I will change by the square root of 21% which is 4.6%." Wrong again, because of air compressibility.

The first approach, 21% decrease in jet size, would likely be too lean. The next try, 4.6% reduction, is probably far too rich.

The AMAL rule of thumb says "try 9% and then test." This may be still too rich but is on the *safe* side. It seems a shame, after expending all this

Three types of main jets sometimes distinguishable by appearance, but don't depend on it. Identification numbers on types labeled "Mikuni" and "AMAL" are indicative of *flow rate* and as you can see, flow rate in cubic centimeters per minute is very nearly proportional to the identification numbers. The jet labeled "Reverse" is stamped with hole *diameter* rather than flow rate. As explained in the text, fuel flow is proportional to diameter-squared therefore a small increase in jet size number produces a large increase in fuel flow. It's helpful to know what your jet size numbers mean, but if you can't find out you can still tune properly by plug readings and performance testing.



time and energy in getting smarter, that we wind up using a rule of thumb. At least we know why.

JET SIZES

The "size" of a jet is normally indicated by a number stamped on it. Larger numbers mean a larger size, however there is some ambiguity in the literature as to what size means.

Jets have been, and are, sized in several ways:

- The diameter of the hole in millimeters or inches.
- An arbitrary numbering system in which the numbers don't have any physical significance, except that larger numbers mean larger jets.
- The flow rate, in cubic centimeters per minute with some standard head.

Most modern motorcycle carbs use either diameter or flow rate to identify jets. Since flow rate (area) is proportional to diameter squared, the distinction is important. However, it is often difficult to find out what system is used in a particular carburetor.

The chart on the preceding page, taken from a Kawasaki manual, shows the difference. The two jet types identified as AMAL and Mikuni are numbered by flow rate. If the number is 200, the curves show that they flow approximately 200cc per minute. The jet type labeled "Reverse" is stamped according to its diameter. As you can see, the flow rate is very nearly proportional to diameter squared.

In some carburetors, Mikuni uses the Reverse Type jet. Some European carburetors identify jets by diameter rather than flow rate.

Obviously, when you change a main jet, you test and take spark-plug readings to find the result.

Needle jets are calibrated by diameter because flow rating would be meaningless. It depends on which needle is used, and the position of the needle in the jet.

AVAILABLE SIZES

AMAL and Mikuni are representative carburetors, and described below. Identification schemes may vary with other manufacturers, however the range of available sizes will be similar.

MIKUNI CARBURETORS

Main jets–
50 to 195 in steps of 5 units
200 to 500 in steps of 10 units

Idle jets–
15 to 80 in steps of 5 units

Needle jets–Size indication is diameter of hole in mm. Available in steps of 0.005mm and identified by code stamped on jet, such as P-2. The letter denotes size increments of 0.05 and the numbers (0 through 9) signify step-increases of 0.005. For example, a P-3 is larger than an O-3 by 0.05. A Q-5 is larger than a Q-4 by 0.005. The next step larger than a P-9 is a Q-0 which will be larger by 0.005.

Needles–Needles are identified by a code stamped on the needle, such as 6DH3. The first number indicates the overall length of the needle. The following letter, or letters, indicate the taper of the needle. If there is one letter, the taper is uniform. If there are two, the taper changes about midway along the tapered section. The first letter denotes the taper of the upper part, the second letter indicates the taper of the lower part.

Starting with letter A, which has a meaning of 15 minutes of arc, each letter in sequence adds an additional 15' to the angle between the two sides of the needle.

A double-taper needle allows "fine tuning" by choosing different tapers for the two sections. A GL taper, for example, has an angle of 1°45' at the top and 3°00' at the bottom.

A GH taper would give about the same mixture at around 1/3 throttle, but would be slightly leaner at around 2/3 to full throttle.

The number following the letter, or letters, is a manufacturing-control number and does not relate to needle size.

In a carburetor specification for a particular motorcycle, the needle identification number, as shown above, may be followed by another number, separated by a dash or in parentheses. If so, the number indicates the groove used for the needle clip, counting the top groove as number one.

Overall flow-rate changes are accomplished by changing the needle jet. Flow-rate changes due to throttle-slide movement are controlled by the amount of taper of the needle.

Throttle slides–Throttle-slide cutaway is indicated by a number stamped onto the slide. A larger number signifies more cutaway.

AMAL CARBURETORS

Main jets–
0 to 50 in steps of 2.5
55 to 150 in steps of 5
160 to 600 in steps of 10
620 to 1000 in steps of 20
1100 to 2000 in steps of 100

Idle (pilot) jets–
Available in steps of 5 numbers.

Current AMALs for four-strokes do not have a removable idle (pilot) jet. A fixed orifice (bushing) is installed at a different location in the carburetor. The threads where a normal idle jet would be screwed in place are deliberately damaged at the factory.

Needle and needle jets–AMAL specifies needle and needle jet in pairs (by part numbers), one set for four-strokes and another set for two-strokes.

For use with the current AMAL Concentric carburetors, Models 600, 900, and 1000, the following pairs of part numbers should be used in sets.

Series 600:

Four-strokes	-	622/122 & 622/124
Two-strokes	-	622/079 & 622/063

Series 900:

Four-strokes	-	622/122 & 622/124
Two-strokes	-	622/079 & 928/063

Series 1000:

Four-strokes	-	622/122 & 622/124
Two-strokes	-	622-079 & 1034/063

The first part number in each set above is the needle jet. Size is designated by a number stamped on the jet which is the diameter of the hole, in thousandths of an inch.

Needle jets are available as follows:

104	105	106	107
108	109	113	120

Throttle slides–Made in steps of 1/16-inch. The number 3, for example, will have a cutaway of 3/16-inch.

LARGER CARB?

Sometimes riders install a larger carburetor on an engine in order to improve high-RPM breathing.

The reason this helps is the fact that the pressure drop across the carburetor will be less if there is a bigger air passage.

When we started to look at venturi action, we assumed that the exit velocity and pressure was the same as the entrance values because we neglected friction losses.

In the real world, this does not happen, and there will be a pressure drop across the carburetor (and the other air passages) which is not due to venturi action but results from air friction against the side of the air passage. This pressure drop can be considered a pumping loss.

The importance of the pumping loss is that it subtracts from the pressure we can get into the engine. If the outside air pressure is 15 psi and the loss across the carb is 5 psi, then the most pressure that can exist in the engine is 10 psi. The friction losses in the carburetor and inlet system would cost the engine 1/3 of its power capability.

Switching to a larger carb reduces air-friction loss because less of the air column is in contact with the side of the air passage. The area of a circle is proportional to diameter squared, whereas the circumference is proportional to diameter (not squared).

Doubling the diameter will allow four times as much area, but only two times as much surface contact. The result is a smaller pressure loss across the carburetor and more pressure in the engine at the end of the inlet phase.

Doing this causes a minor and a major problem.

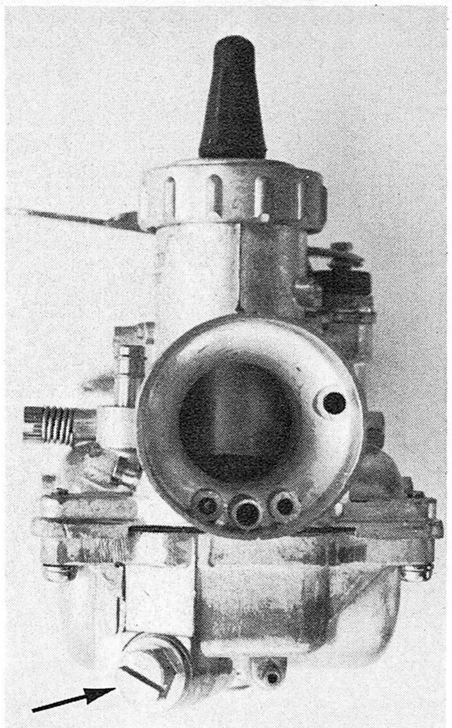
The minor problem is to select the right size main jet for the larger carburetor. The jet change will be proportional to the square of the diameter change in the carburetor.

$$\text{New Jet} \sim \text{Old Jet} \left(\frac{\text{New Carb Size}}{\text{Old Carb Size}}\right)^2$$

Once again, the change will be different than the calculation suggests because a larger venturi will reduce air velocity for the same weight of air flowing. The venturi depression will not change linearly with air flow on account of compressibility. The change calculated by the above will serve as a starting point, from which correct jetting can be found by testing.

FLAT SPOT!

The major problem resulting from change to a larger carburetor is a "flat spot" in the acceleration performance of the machine. Nearly every rider who tries a larger carburetor experiences this.



Main jet on this Mikuni is accessible through hex-head screw at bottom of float bowl. Since most carb adjustments are simply main jet and needle position, this is very handy!

The problem results mainly from the fact that the level of fuel in the float bowl must be below the outlet into the venturi, so gasoline doesn't flow out into the carburetor when the bike is parked at an angle or being ridden on hills.

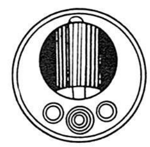
Because the fuel is below the fuel nozzle (needle jet) in the carburetor throat, the venturi depression must first lift the fuel up to the level of the nozzle before any fuel can flow. Then, some additional depression can cause the fuel to flow into the air stream.

When the carburetor bore size is made larger, the venturi pressure drop is less for the same amount of air flow. Therefore, at open throttle, a higher amount of air flow is required in order to start fuel flow through the needle jet, and the rider feels a flat spot.

If the rider opened the throttle only a little bit, he could create enough suction to make the fuel flow, the same as on a small carburetor. However, riders who put on big carbs are rarely inclined to use part throttle while accelerating, so the problem exists.

Raising the fuel level in the bowl may help some, but the limit is spilling over at angles. Enriching the idle settings can help because the idle system continues to function as the throttle slide is lifted off its stop and has some effect up to about 1/8 open. A smaller amount of throttle cutaway may also help, for a similar reason.

Most carburetor literature is based on fixed-venturis and offers the opinion that flat spots are inevitable when carburetor size is increased. They are not inevitable with a variable venturi under control of the operator, however the cure is against human nature and seldom applied.



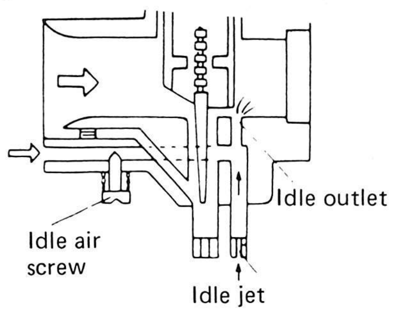
IDLE SYSTEM

Imagine you are lowering the throttle-slide gradually, and the venturi passage is getting progressively smaller. At some very small opening, one or both of two things can happen. The air velocity to supply the needs of the engine can increase until it becomes sonic (the speed of sound). Above sonic velocity, normal venturi action ceases.

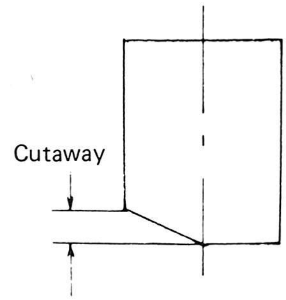
Also, as the air passage becomes smaller, the friction losses increase rapidly. At some small throttle opening, the air passage becomes a tunnel of relatively long length and small area. The pressure loss due to friction may be 10 psi. If the fuel nozzle is midway along the air passage, then it will experience a pressure drop of 5 psi below outside air pressure. This drop is due to air friction and in addition to venturi depression.

Either or both of the above conditions will cause the carburetor to stop behaving normally and controllably. The solution is to use a separate, auxilliary system to supply the idle mixture.

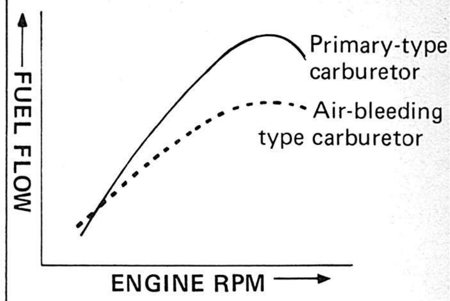
The throttle stop screw, or some other arrangement, will stop the throttle-slide before it closes completely. Some air and some fuel will flow through



IDLE CIRCUIT



THROTTLE SLIDE CUTAWAY



FUEL FLOW
(at constant throttle-valve opening)

The main difference between a primary-type carb and an air-bleeding or emulsion tube type is the fuel-flow characteristic shown by these two curves. At constant throttle-opening, increased engine RPM means higher velocity of air flow through the carb. With increasing air velocity, primary type increases fuel flow at a higher rate than does the emulsion-tube type. Choice is made at the factory according to engine design and mixture requirements.

the main air passage, augmented by air and fuel from the idle system. Control of the F/A ratio is accomplished by the idle system adjustments.

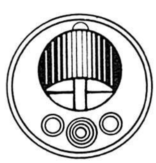
The "suction" to draw air and fuel through the idle system results from the high pressure drop across the nearly closed throttle-slide. The idle system opens into the main air passage of the carb at a point behind the throttle-slide and as long as this point has low pressure, air and fuel will flow through the idle passages.

When the throttle-slide is lifted, the pressure drop behind the slide becomes less, and the idle system gradually ceases to operate.

SLIDE CUTAWAY

There is a transition between idle-system operation and the normal venturi action of the carburetor. In this transition, idle flow is reducing and flow through the main passage is increasing.

We have adjustments for idle operation and for mid-throttle operation. A further adjustment is needed for F/A ratio during the transition away from idle, called *off-idle*, surprisingly enough.



This is accomplished by the throttle-slide cutaway. The amount of cutaway, or taper, affects the friction losses through the carb bore when the opening is small, because it affects the shape of the "tunnel." It therefore affects the pressure drop felt by both the needle jet and the idle-system port in the main air passage.

Varying the amount of cutaway will change the fuel-flow characteristics during the transition period. Increasing the amount of cutaway produces less suction and a leaner mixture.

If the bike does not pick up speed smoothly, from idle, and the throttle has not been cranked all the way open at the time, then a smaller cutaway is indicated, to give a richer mixture.

The amount of cutaway is indicated by a number stamped on the slide. The number can mean fractions of an inch, or millimeters, however a larger number will mean a larger cutaway.

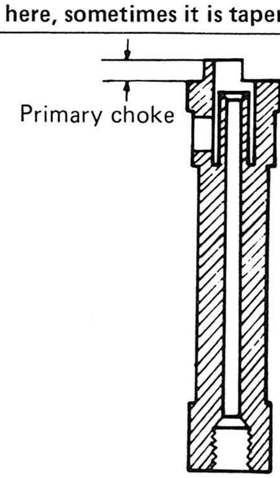
When the throttle is opened completely, the bottom of the slide may be pulled clear out of the bore, or it may be flush with the top of the bore. In either case, the cutaway portion is so high it is ineffective. If a bike will not pull away from stop smoothly, when the slide is jerked all the way to the top of its travel, the fault is not with throttle-slide cutaway. It's your right hand.

AIR BLEED

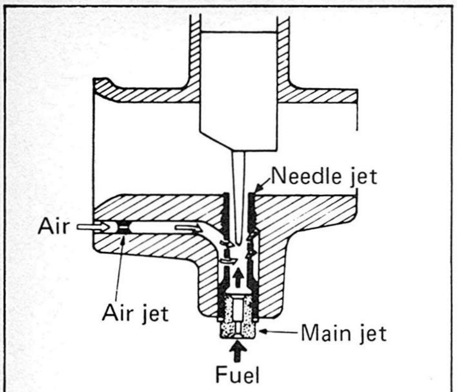
Usually there are two small openings at the front of the venturi on a carburetor. One is the idle-air passage, as discussed.

The other will be the air-bleed entry. The passage from this opening leads directly to the vicinity of the needle jet. Its purpose is to feed a supply of air, during normal operation, which mixes with the fuel going into the main air passage. This premixing results in delivery of a foam, or emulsion, of air and fuel into the main air stream and aids in breaking the fuel into

Height of primary choke is amount that sticks up into bore of carburetor. Sometimes primary choke is cut off square as shown here, sometimes it is tapered.



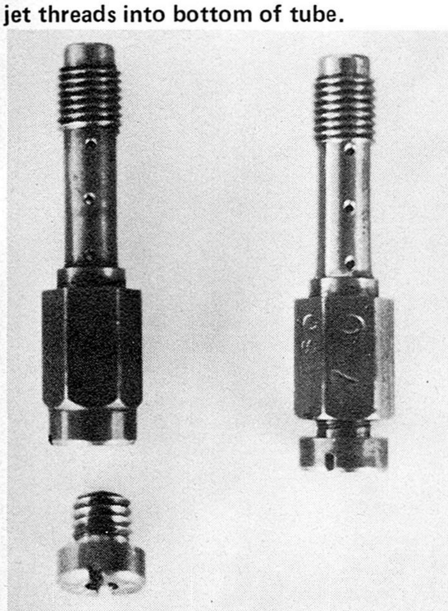
PRIMARY CHOKE CONSTRUCTION



AIR-BLEEDING TYPE CARBURETOR

This is an "air-bleeding type carburetor" more properly known as an emulsion-tube type because the primary type also bleeds air to the vicinity of the needle jet. Names are confusing but drawing shows the difference. Here, bleed air is brought through holes in the tube between main jet and needle jet and mixes with the fuel *before* passing through the needle jet. Tube with holes in it is called an emulsion tube.

Emulsion tube threads into carb body above holes in the tube which admit bleed air. Needle jet is part of emulsion tube—needle enters orifice at top of emulsion tube. Main jet threads into bottom of tube.



small droplets so it will vaporize more readily. It also tailors the mixture to be more nearly what we'd like.

Vaporization occurs on the surface of fuel. An amount of fuel broken up into small droplets has much more surface area than the same amount of fuel in one big glob.

Air bleed is done in two ways. In one method, the air is brought to a cavity around the end of the needle jet and mixes with the fuel as the fuel emerges from the jet.

This is sometimes called a "primary type" carburetor because an extension of the needle jet protrudes into the carburetor main air passage. As air flows past this *primary choke*, vacuum is created on the lee side, which induces air flow through the bleed-air passage.

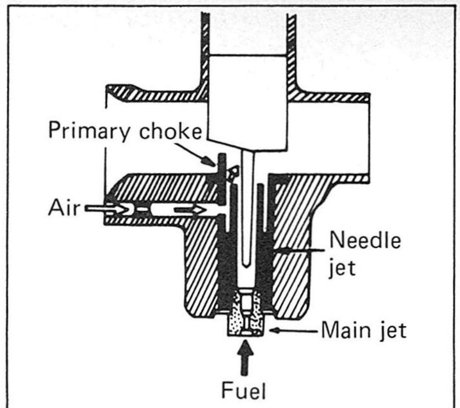
Another way is to bring the bleed-air into a cavity which surrounds the tube between the main jet and the needle jet. This tube will have small holes drilled into it and, when so constructed, is usually called an *emulsion tube.* The bleed-air enters the tube through the holes and travels upward and out through the needle jet, mixing with the gasoline as it goes along.

A secondary advantage of using an emulsion tube is that the foamy mixture flows through the tube and jet more readily. Emulsion tubes can always be identified by the holes drilled into them.

When bleed-air is brought into the emulsion tube, the reduced pressure causing air flow is the same as the reduced pressure causing fuel flow—the venturi depression. Consequently, this type of carburetor does not require a projection into the bore of the carb. The emulsion-tube type is sometimes called an air-bleeding carburetor to distinguish it from the primary-choke type. Both types bleed air.

The flow-rate characteristics of the two types are different, as indicated in the curves shown. Choice is determined by the designer of the engine.

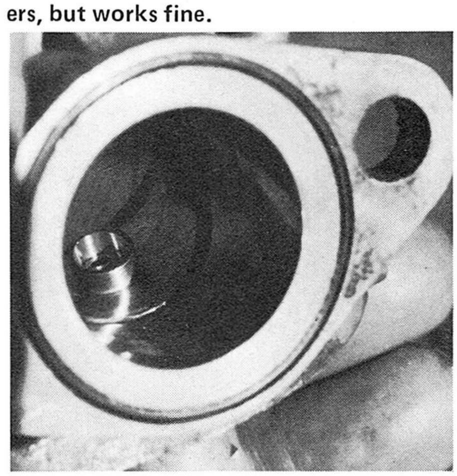
With either method, more bleed-air reduces the amount of fuel flow and tends to lean the mixture. An adjustable bleed-air orifice is sometimes used as a form of mixture control, however on most carburetors this is not a tuning adjustment. The effect of bleed-air is most when the venturi depression is highest, full throttle and max RPM.



PRIMARY-TYPE CARBURETOR

Bleed air in this type of carburetor flows to a cavity which *surrounds* the needle jet and mixes with the fuel *after* fuel has gone through the needle jet. A barrier is placed in the bottom of the carb passage, ahead of the bleed-air port, which reduces pressure on the downstream side to aid induction of bleed air. This barrier is usually called a primary choke and a carb using this bleed-air method is usually called a primary-type carburetor.

Doesn't pay to get hung up on nomenclature. This Spanish AMAL carb uses an emulsion tube but surrounds the end of it with a tapered primary choke. Carb is mixture of both types, neither fish nor feathers, but works fine.



ACCELERATION FUEL SUPPLY

When the throttle is suddenly opened, the mixture tends to become momentarily lean, unless additional fuel is supplied. The reason is that air flow increases before fuel flow can increase, due largely to the inertia of the fuel.

Automotive carburetors use an accelerator pump which squirts an extra charge of fuel into the air flow when the throttle is moved quickly.

Motorcycle carbs generally rely on the small amount of fuel which stands above the main jet, in the fuel-supply tube to the needle jet. With an emulsion tube, during static conditions, some fuel can reside in the cavity surrounding the tube. This fuel, above the main jet, is more readily available to sudden demand, because it does not have to flow through the restriction of the main jet.

PERCOLATION

When an engine has been running long enough to reach the normal operating temperature, and is then shut off, it is sometimes difficult to restart. When finally started, it smokes, gargles, and exhibits signs of extreme richness.

The reason for this is that the engine temperature gradually raises the temperature of the fuel in the float bowl. Since fresh, cool gasoline is not continuously flowing into the bowl, the gasoline will reach a temperature higher than normal. The elevated temperature can cause the gasoline to boil and make bubbles of gasoline vapor.

This is similar to what happens in a coffee percolator, except that gasoline boils at a lower temperature than water. Bubbles of gasoline vapor rise up in the tube between main jet and needle jet, forcing liquid gasoline out into the throat of the carb. When you try to start the machine, it is over-rich.

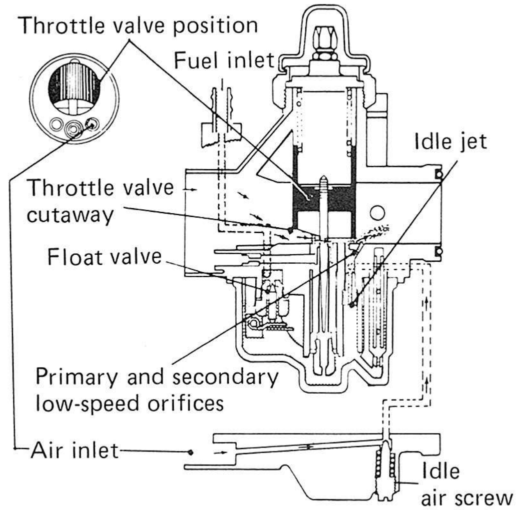
An emulsion tube reduces the percolation problem because the rising bubbles of vapor can escape through the holes in the tube.

With any carburetor, if the rider remembers to turn off the fuel first, run the engine a few seconds, and then switch off, hot starting problems are minimized.

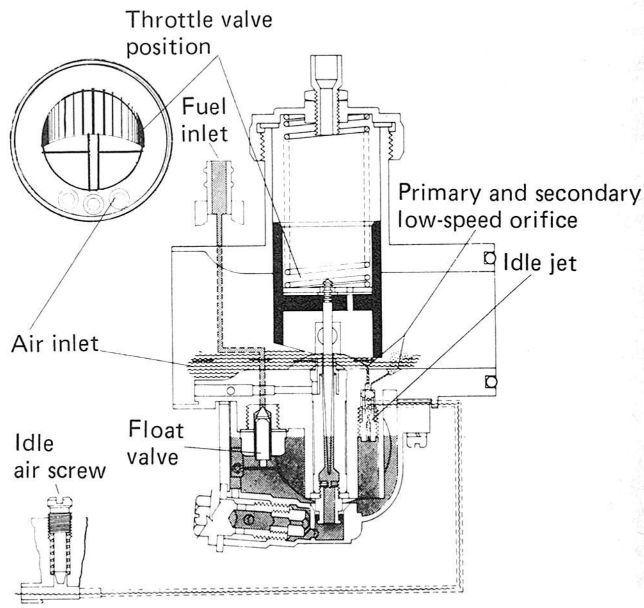
Drawings courtesy of Pabatco and Hodaka.

SO HERE'S HOW IT WORKS

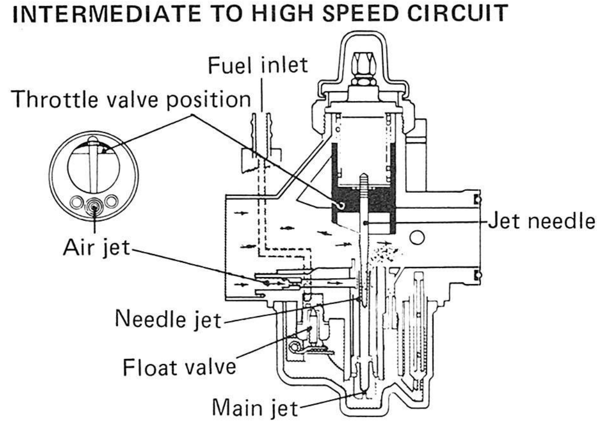
IDLE TO INTERMEDIATE SPEED CIRCUIT



INTERMEDIATE CIRCUIT



INTERMEDIATE TO HIGH SPEED CIRCUIT



Mikuni Carburetor

Cutaway drawings kindly furnished by Pabatco show Mikuni carb as used on some models of Hodaka motorcycles. Carb is shown with three different amounts of throttle opening, illustrating different modes of operation as described in text.

STARTING MIXTURES

When the engine is cold, the fuel drawn into the cylinder will not vaporize readily, or as completely as in a warm engine.

The cranking RPM of an engine is low, resulting in low air velocity through the carburetor and poor atomization of the fuel.

As a result, an engine needs a very rich mixture to start from cold because much of the fuel will not enter into the combustion process.

Carburetors provide an enriched starting mixture in several ways. The simplest is the "tickler," which is a spring-loaded rod which extends into the top of the float bowl. Pushing the tickler down causes the float to move down and unseats the valve.

Fuel flows into the bowl and the fuel level rises, reducing the head necessary to cause fuel flow out through the needle jet. The low-velocity air flow thus takes up more fuel.

Another method is to close off the inlet side of the carburetor air passage (choking) which creates a very high depression behind the choke and pulls more fuel from the float bowl. On some motorcycle carburetors, the choke is called the *air lever.*

Other methods include a separate starting system, similar to the idle system, which is opened by a lever.

Examination of your owner's manual or your carburetor will disclose which system your machine uses. These are not tuning adjustments and rarely get out of order.

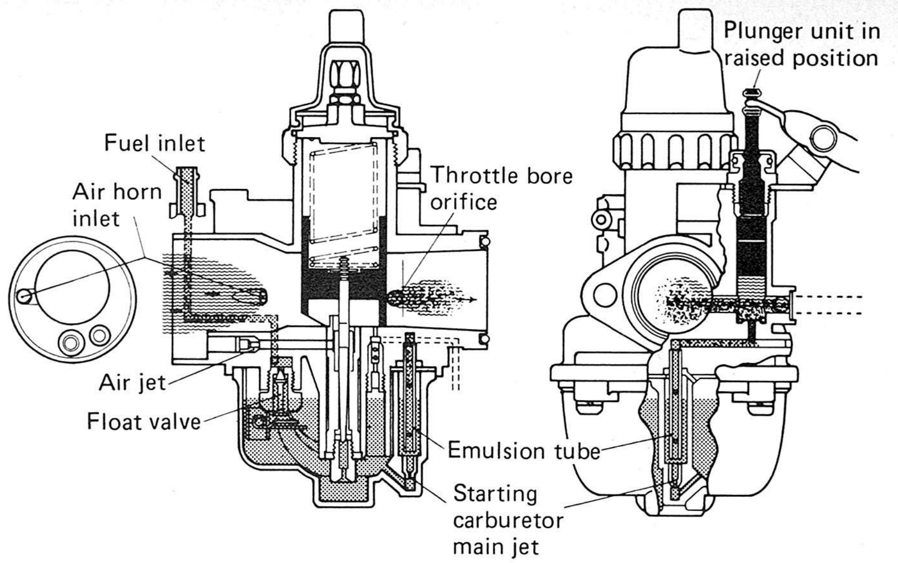
C-V CARB

The Constant-Vacuum carb is a good example of theory put to work. You will recall, earlier, we determined that a variable-venturi solves the air compressibility problem by operating so as to keep the venturi depression constant.

When this is done manually, by the rider, the adjustment of venturi area for air flow may not be done accurately.

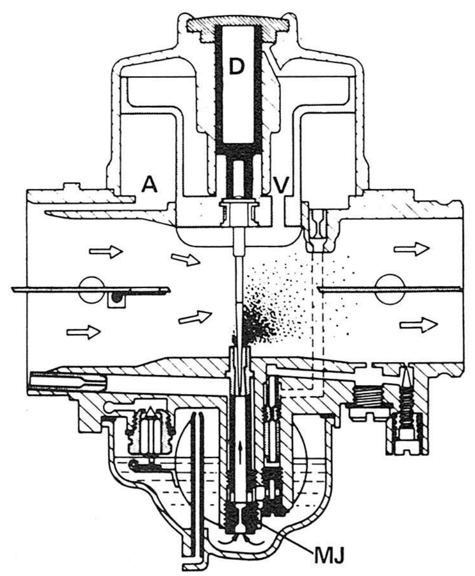
A C-V carburetor uses a separate throttle, between the carburetor and the engine, which is controlled by the rider. The throttle-slide no longer has the job of "throttling," so we will call it the venturi-slide in this type of carburetor.

The function of



MIKUNI CARBURETOR

This Mikuni carburetor uses a separate "starting carburetor" built into the body of the unit. Air enters the hole on the side of the air horn. Fuel from the float bowl is ducted to a separate starting carburetor main jet. Fuel and air merge in a chamber and are led to an orifice in the side of the throttle bore, behind the throttle-slide. The choke lever raises or lowers the plunger. When lowered, it closes off both fuel and air.



OPERATION OF THE C-V CARBURETOR

Drawing courtesy of American Honda.

Throttle is fully open, venturi slide is all the way to the top. Main jet (MJ) is metering fuel. Outside air entry to bottom of piston is through passage A and venturi depression is transmitted to top of piston through opening V. Dashpot D prevents flutter.

the venturi-slide is only to control the size of the venturi, and this is done by automatically sensing the air flow.

At the top of the carb is a piston which operates up and down in a bore. Movement is governed by the differential air pressure on the top and bottom sides of the piston.

Outside air pressure is led into the volume beneath the piston through a hole leading from the front of the carburetor. The venturi pressure is brought to the top of the piston through a passage in the carburetor body, or through a hole passing up the center of the piston.

When venturi pressure drops, due to increased air flow, the pressure on the top of the piston becomes less with respect to the outside air pressure on the bottom. The piston moves up.

Suspended from the bottom of the piston is the venturi slide which enters the main air passage of the carb, the same as the throttle slide in a conventional motorcycle carburetor. Suspended from the bottom of the venturi slide is the needle, also similar to a conventional carb.

When the piston rises, the slide is pulled up and the venturi area is increased. This causes the venturi pressure to return to a value about the same as it was before the piston and slide moved up.

This can be understood by remembering that the piston and slide combination has some weight and, when the piston is lifted up any amount above its stop, the weight is suspended by the pressure difference across the piston. Since the weight is constant, the pressure difference will be constant. Since outside air pressure is reasonably constant, then the venturi pressure will be held reasonably constant also, by movement of the piston.

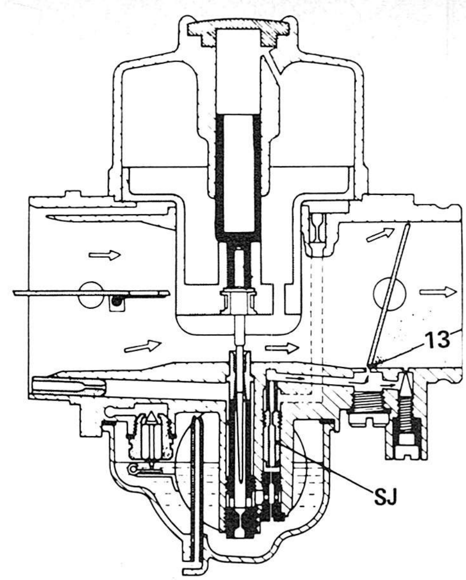
Some constant-vacuum carbs have a coil spring above the piston, so the spring pressure is added to the weight of the piston. The principle is the same. Also, some of these carburetors use a dashpot to prevent the piston from fluttering due to the air pulses which pass through the venturi as the inlet system of the engine opens and closes, and to provide momentary enrichment for acceleration.

When the rider opens the throttle, he is merely advising the engine and carburetor of his intent to go faster. They do the rest of the job, smoothly and automatically.

It is not desirable to have the venturi-slide leaping up and down in response to each pulse of air into the engine. The C-V carb should respond to the average air flow and respond to changes in the average.

Averaging is easier if one carburetor serves more than one cylinder, or if there is a log manifold interconnecting individual carburetors serving individual cylinders. This tends to keep some air flow through each carburetor all of the time.

On account of symmetrical port timing on some two-strokes, the intake period is shorter than on most four-strokes. C-V carbs are therefore better suited to use on four-stroke engines.



OPERATION OF THE C-V CARBURETOR

Drawing courtesy of American Honda.

Butterfly choke at inlet is used only for starting enrichment. Throttle plate is just coming off idle and exposing the by-pass outlet (13) of the idle system, which is fed by the slow-running jet (SJ). Venturi slide is all the way down.

Author's first encounter with C-V carb— was on vintage English sports cars where they caused considerable puzzlement to young lad from the farm. They worked fine as long as I left them alone.

English literature on this type of carb (made by SU) is filled with colorful language. One of the principal adjustments is constantly referred to as the gland nut.

Which makes it difficult, when tuning on an SU, to explain to somebody exactly what it is you are doing there.

Constant-vacuum carburetor as used by the clever engineers at Honda on the double-knocker 450.
Throttle-plate is on shaft between carb and engine. Throttle stop screw is visible. Lever on shaft between air cleaner box and carb is manually-operated choke. Pressure-controlled piston lives in dome on top of carburetor.
Also known as constant-velocity carb. Call it a C-V and, if it isn't a Czechoslovakian motorcycle, it's a carburetor.

LOADING UP

A frustrating problem among one-cylinder two-strokes is called *loading up.* The engine ingests a very rich mixture and either quits running or has to be coaxed to run while emitting clouds of smoke, gasping, and exhibiting all the signs of extreme richness.

This problem is reduced when one carburetor serves more than one cylinder, and it is usually less severe with four-stroke engines unless they have extreme valve timing.

The cause is reversed flow through the carburetor. On most engines, the inlet is left open during the early part of the following stroke in order to take advantage of the ram effect at higher RPM.

On two-strokes, the inlet port is uncovered by the skirt of the piston, as it moves up, and then must remain open after the piston passes TDC, until the piston comes back down to close the port.

At low RPM and open throttle, ram effect is negligible. Because of the relatively long period of time allowed for the intake event, the pressure in the engine is likely to be close to atmospheric. Thus, when the piston starts down from TDC, it can expel mixture, back out through the carburetor, until the inlet system is closed.

The ejected mixture will pass outwards through the venturi in the carburetor and pick up another load of fuel.

After going outward through the carburetor and receiving the second shot of fuel, the doubly-enriched mixture will then loiter in the carburetor entry and in the interior volume of the air cleaner until the next intake.

When the doubly-enriched mixture is drawn through the carb again, it again picks up fuel, and is now triply-enriched. Fuel-air ratios of twice the correct value have been observed *during low RPM open-throttle operation.*

If the throttle is kept partially closed at low RPM, air velocity is increased and there is some ram effect even at low speeds. Also, the throttle serves as an obstruction to mixture, both going in and going out.

The C-V carburetor solves the problem nicely, for four-strokes, because it won't let the venturi slide remain open while air velocity is low.

On a two-stroke, a reed valve between carburetor and engine will prevent reverse flow and reduce the tendency to load up, even when the rider insists on holding the throttle open at low RPM. A reed valve has other advantages, including asymmetrical timing.

Keeping records—Lots of active people want to tune and ride. Paperwork seems like a bother and a waste of time.

It's the other way around. Keeping records will positively save you time in the long run and will allow you to tune better.

If you have not been doing it, don't judge the method until you have tried it.

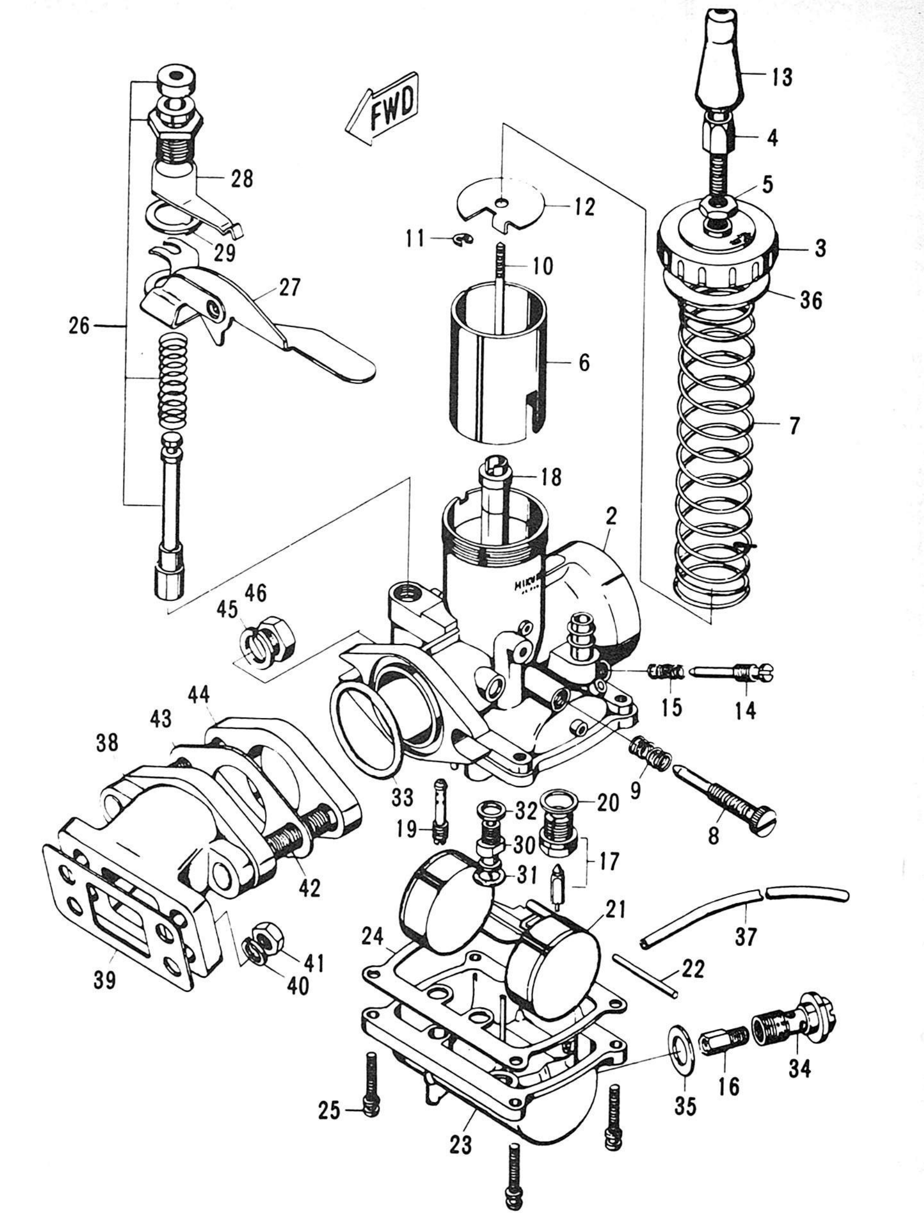
An International Gallery Of Carburetors

Or a Rogues Gallery, if you happen to have strong feelings about any of these makes.

By now, you should be able to take most any motorcycle carburetor apart, identify the pieces and their functions, adjust it as required, and put it back together.

The following gallery of pictures therefore will not contain a lot of explanations of how they work, or call-outs of the parts. The purpose is to make you a little more familiar with the brand you own. The chances are good that you have one of these makes on your bike. And to highlight both similarities and some of the interesting mechanical differences among parts and arrangements.

You have already seen the anatomy of the AMAL, so it is not repeated here.



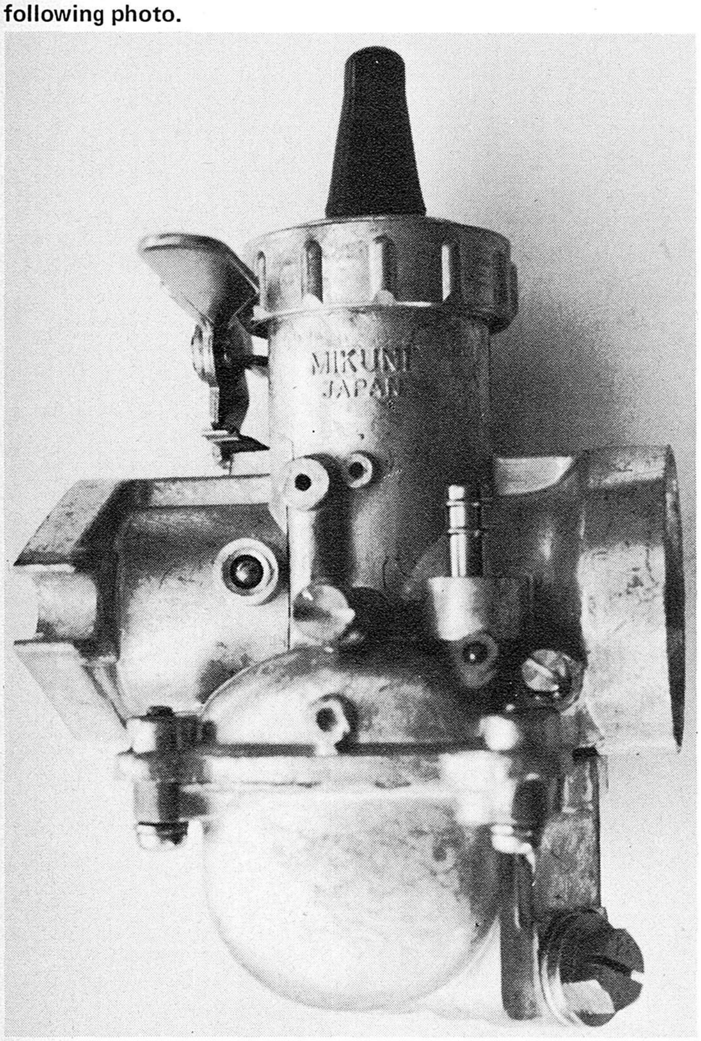
MIKUNI CARBURETOR AS USED ON HODAKA

No.	Name	Quantity Required	No.	Name	Quantity Required	No.	Name	Quantity Required
1	Carburetor assembly (2/37)	1	17	Float valve and seat	1	32	Needle jet washer	1
2	Mixing chamber body	1	18	Needle jet	1	33	Carburetor O ring	1
3	Mixing chamber top	1	19	Pilot jet	1	34	Banjo bolt	1
4	Throttle cable adjuster	1	20	Float valve gasket	1	35	Banjo bolt washer	1
5	Throttle cable adjuster locknut	1	21	Float	1	36	Mixing chamber top gasket	1
6	Throttle valve	1	22	Float pin	1	37	Vent pipe	1
7	Throttle valve spring	1	23	Float chamber body	1	38	Inlet manifold	1
8	Throttle adjuster	1	24	Float chamber body gasket	1	39	Inlet manifold gasket	1
9	Throttle adjuster spring	1	25	Float chamber screw		40	Inlet manifold spring washer	4
10	Jet needle	1		(includes spring washer)	4	41	Inlet manifold nut	4
11	Jet needle clip	1	26	Starter plunger unit	1	42	Inlet stud	2
12	Cable seat	1	27	Starter lever	1	43	Inlet gasket	1
13	Mixing chamber top rubber cap	1	28	Starter lever spring	1	44	Heat shield block	1
14	Air screw	1	29	Starter lever washer	1	45	Spring washer	2
15	Air adjusting spring	1	30	Needle jet bolt	1	46	Nut	2
16	Main jet	1	31	Needle jet O ring	1			

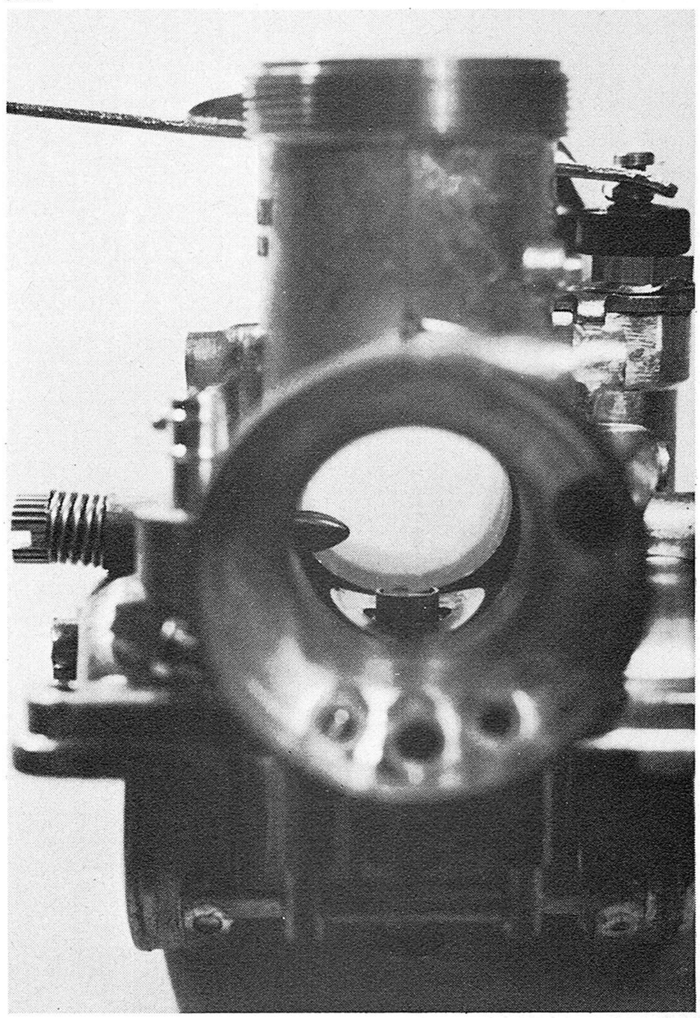
Courtesy of PABATCO, importers of Hodaka.

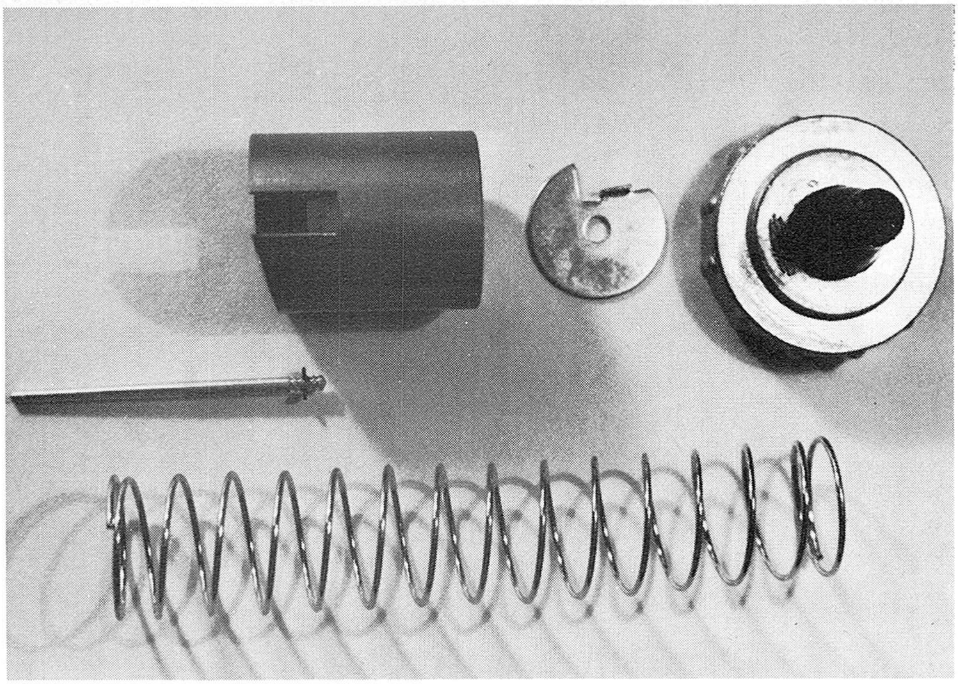
Mikuni

This recent Mikuni is typical of those found on many Japanese bikes, except Honda. One feature of this carb which endears it to some tuners is the fact that the main jet is accessible from the outside through the hex-head screw with the screwdriver slot, at the bottom of the float bowl. This introduces some complexity—and one more thing to worry about—as we will see in a following photo.



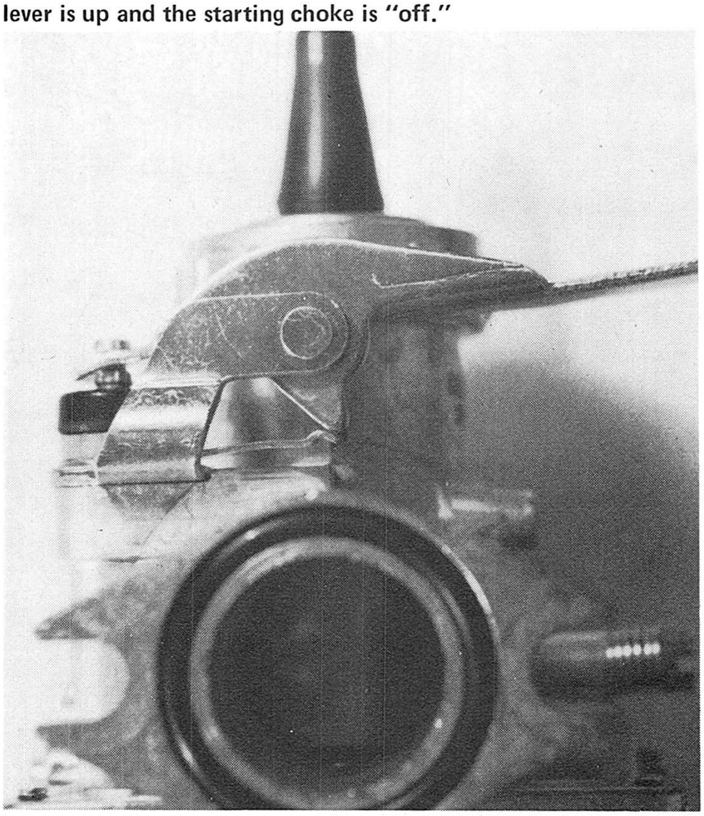
Looking in the front door, the throttle-stop screw is visible in the bore. The starting-choke lever is at the top on the opposite side.



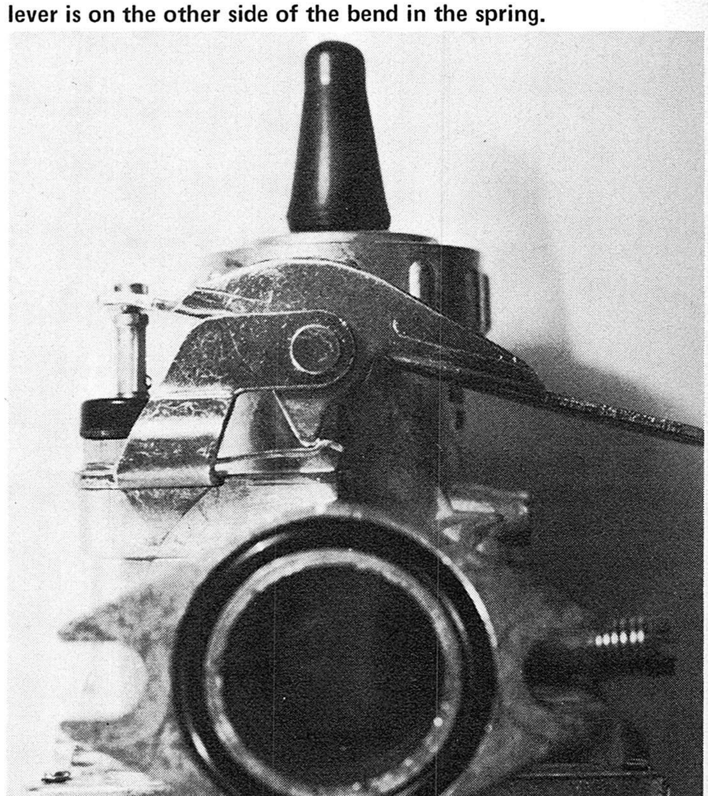


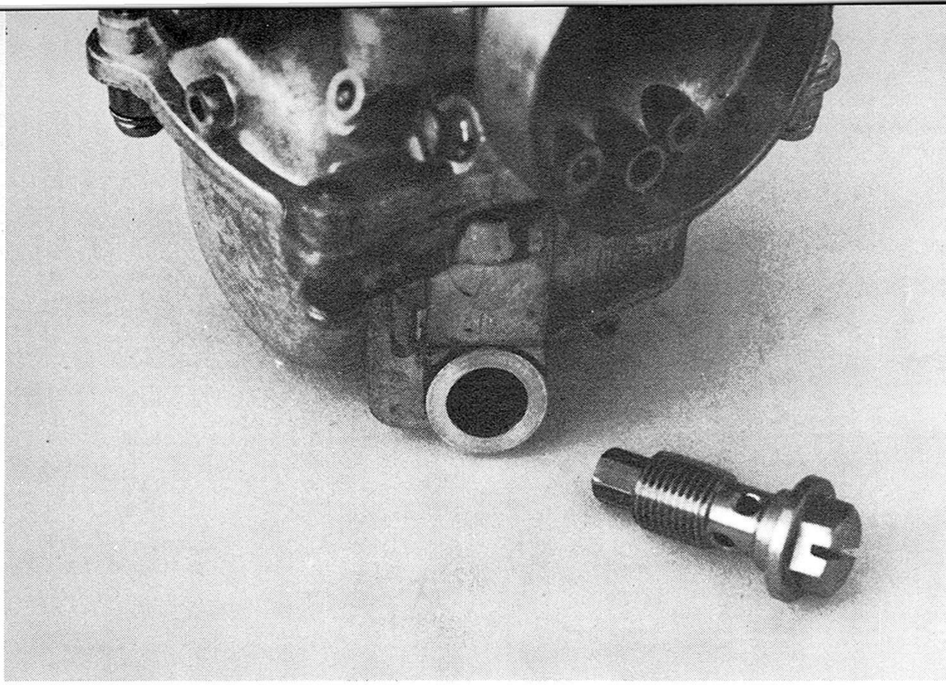
Throttle slide and associated parts. The throttle-stop screw engages the slide on the sloping surface at the top of the groove in the side of the slide. Notice the bent-up tang on the washer between slide and cap. A later shot shows how it fits into the slide.

Ever notice the click-action of the starting-lever when you are riding a bike with a Mikuni? This shot shows what makes that satisfying click. Below the pivot is a detent mechanism, formed by the extension of the pivot arm and the spring. Here, the lever is up and the starting choke is "off."

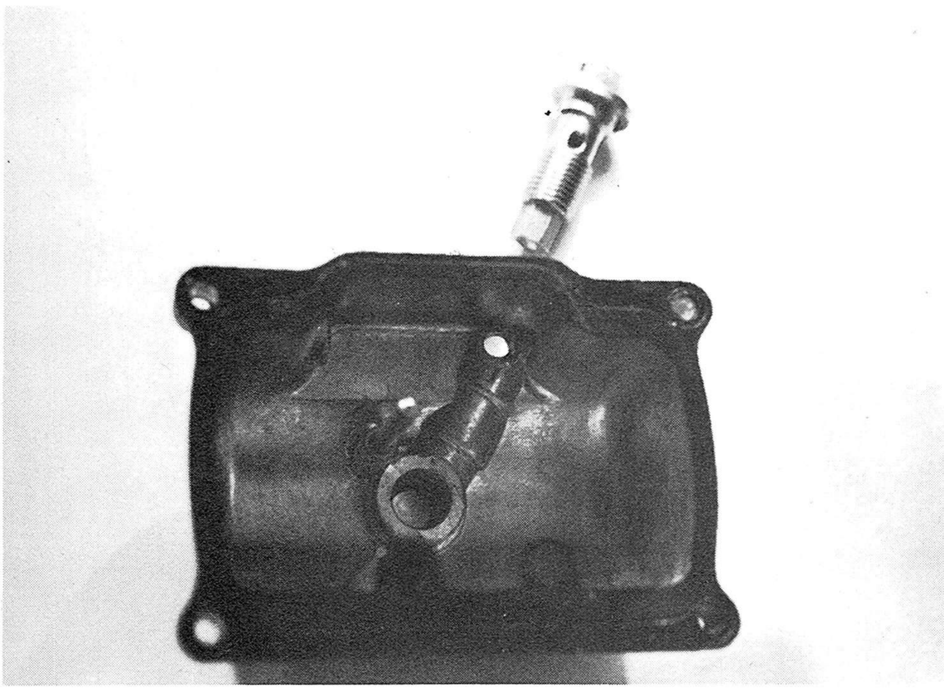


Now the starting choke has been operated and the tang on the lever is on the other side of the bend in the spring.

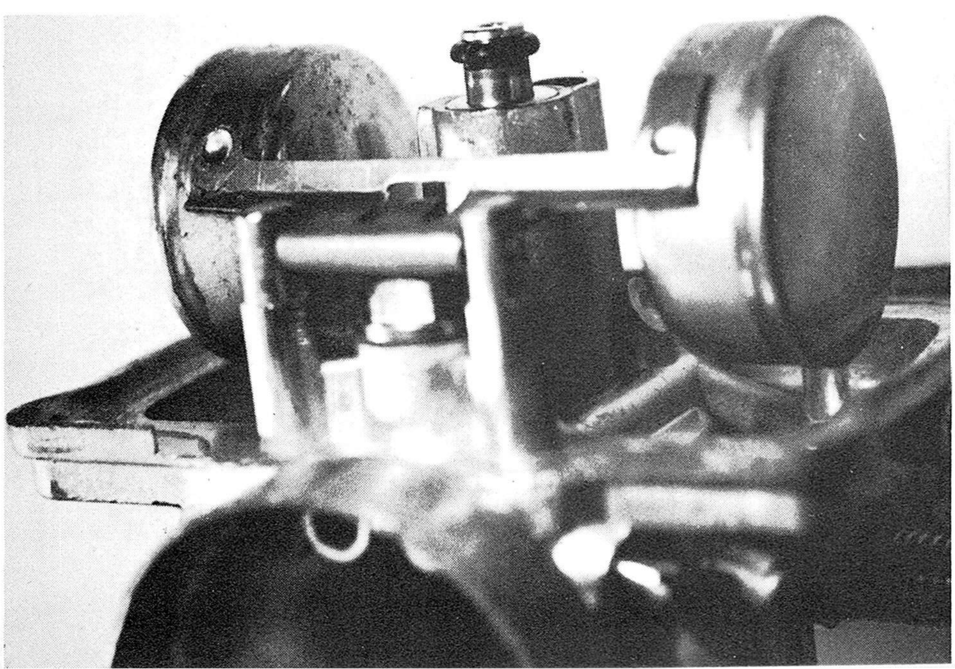




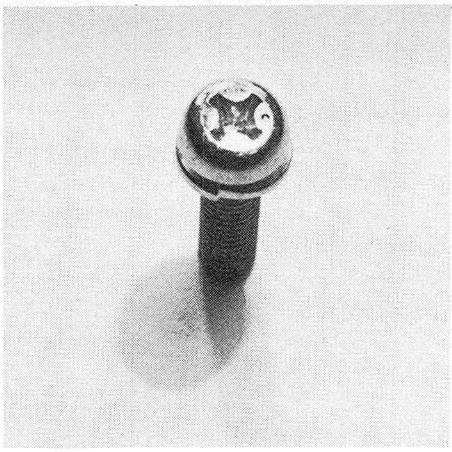
Main-jet holder has been removed from the float bowl. The internal arrangement of the float chamber allows fuel to flow into the holes in this jet holder, between the threaded part and the head. When installed, the threaded section forms a barrier and the path for fuel flow is along the inside of the jet holder, emerging at the far end through the center of the hex-shaped main jet. The *only* main-circuit metering is the jet at the end of this holder.



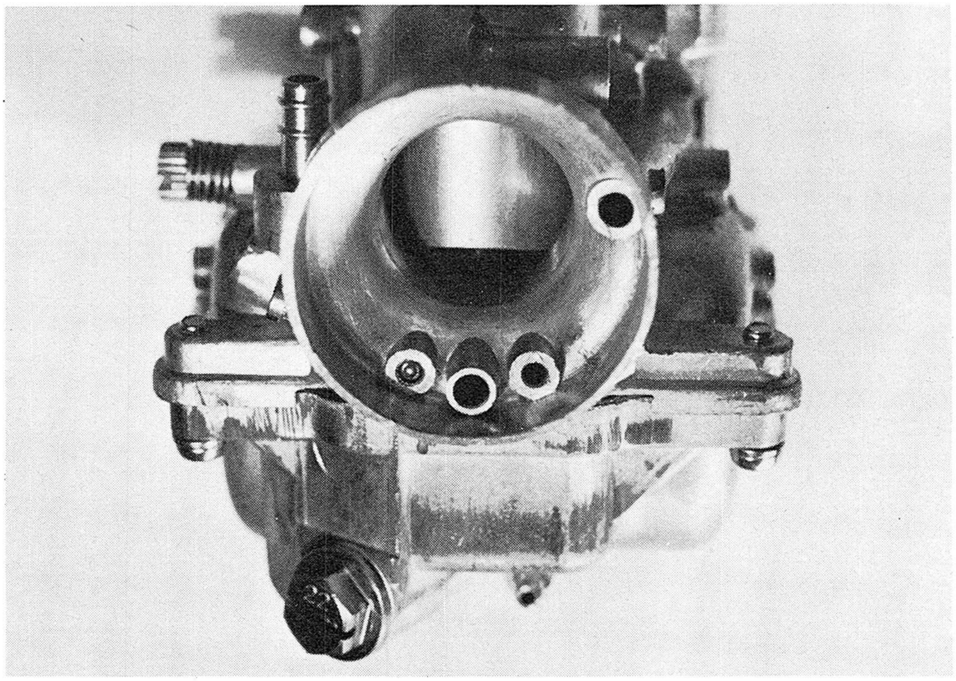
Looking down into the float bowl, the main-jet holder fits into the tunnel at the bottom. Fuel flows down through the hole near the outer edge of the bowl, back toward the center of the bowl through the inner passage of the jet holder, through the main jet, and into the well at the bottom of the bowl. The standpipe next to the well is an overflow tube.



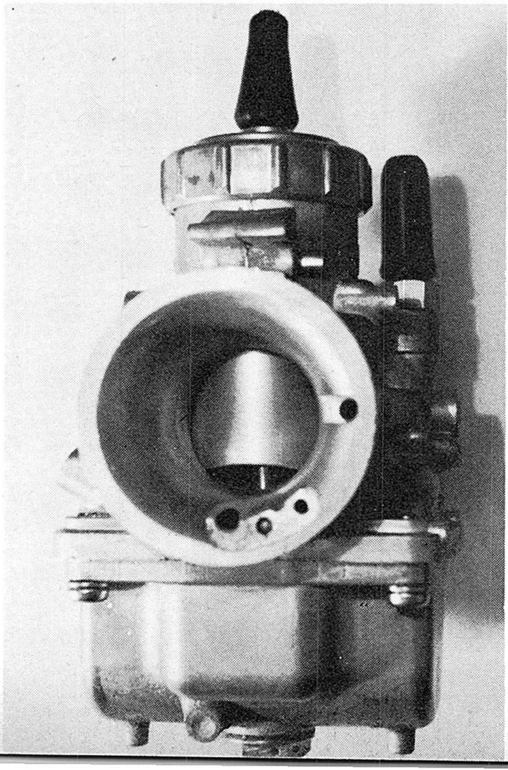
Bottom of the carb, with the float bowl removed. Between the two float halves is the fuel tube which goes up to the needle jet. Notice the rubber O-ring around the bottom of this fuel tube. When the parts are put together, this tube fits down into the well in the float chamber and the O-ring *must* provide a seal around the tube. *If this ring is damaged or not properly sealing, fuel from the float chamber can enter the well directly, by-passing the main jet.* The price for the convenience of the external main jet is this vulnerable little O-ring, and spares are advisable.



This is one of the screws which hold the float bowl in place. Notice the small punch mark on the head, beside the indent for a screwdriver. This little dimple tells you that the threads on this screw are ISO (International Standards Organization). If you lose the screw and replace it with one from your junk box, you will destroy the threads in the carb body and make your friendly parts man chuckle. ISO is a thread pattern different from standard metric and of course from standard United States thread profiles. Watch for punch marks on screw heads and the word "ISO" on carburetors, engines, and bike frames. When you see it, be wary of replacing screws except with exact part-number duplicates.

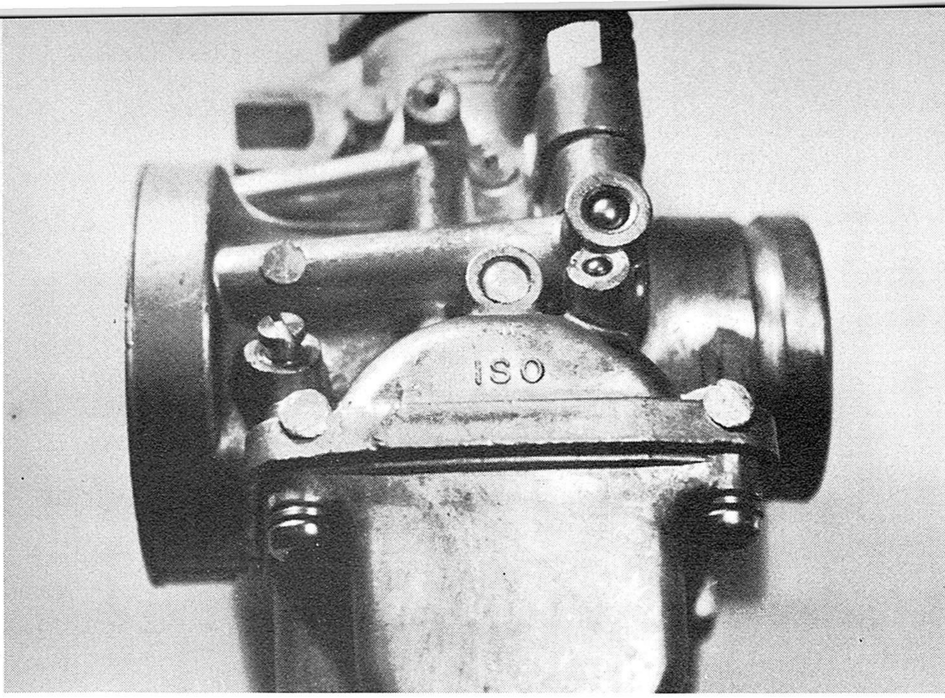


Last look at a standard Mikuni. You know what the air holes in the bell are for, but notice the shapes and protuberances and think about what these irregularities might do to the air flow pattern into this instrument.

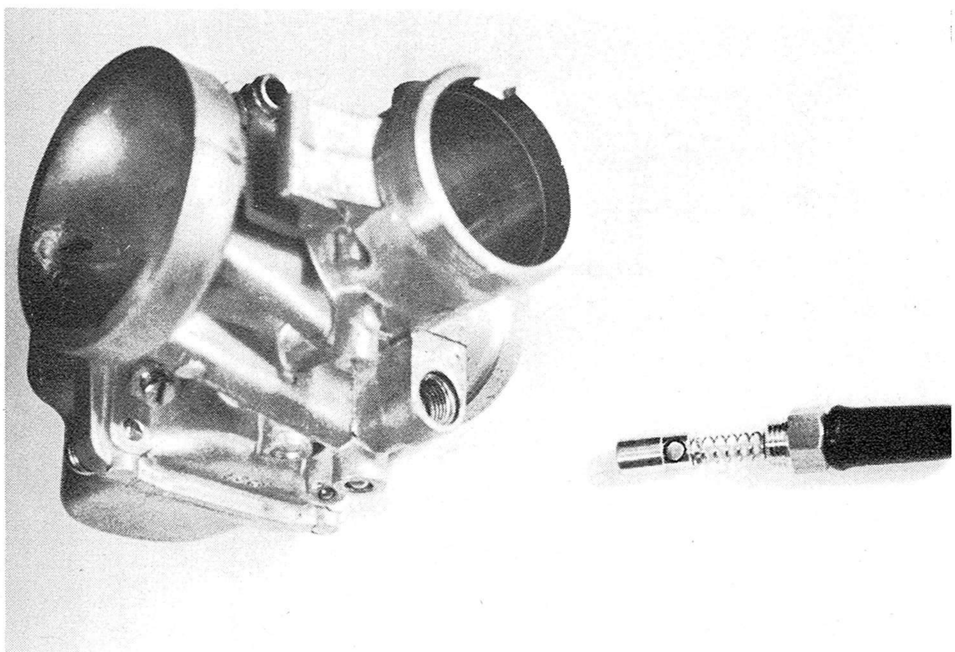


MIKUNI ROAD-RACING CARBURETOR

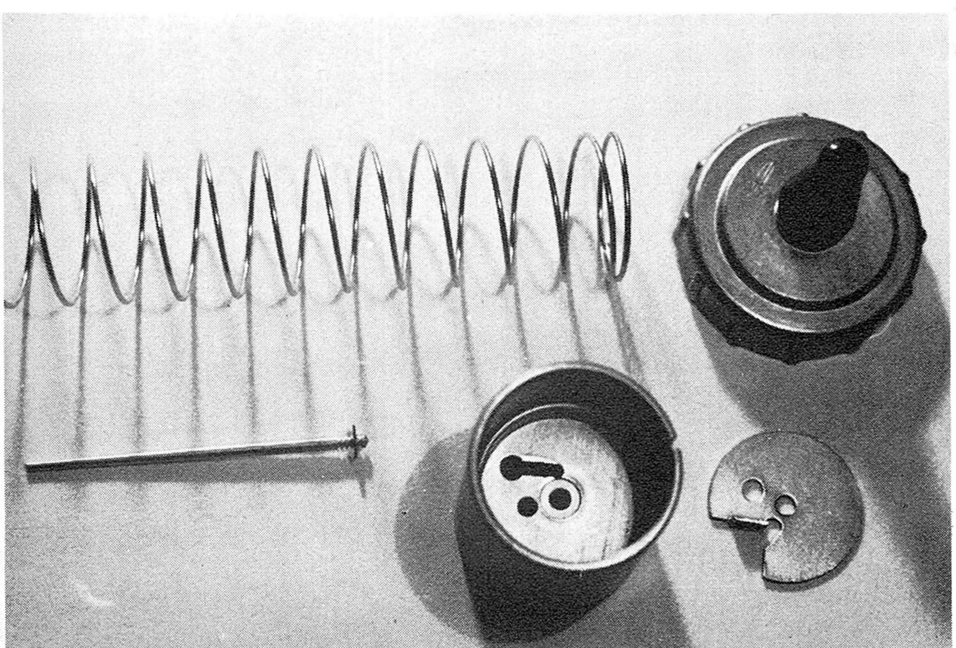
This is the Mikuni model commonly referred to as the road-racing version. The principal *functional* difference is in the shape of the bellmouth at the air inlet. The profile is smoother because the auxiliary-air-passage protuberances are ground away. There are some mechanical differences in this carb which are interesting, but the main difference is air flow into the mouth. This explains why tuners sometimes report a gain in horsepower on the dyno when they substitute the road-racing carb. Notice that the starting choke on this model is set up for remote operation by a cable, rather than a lever mounted on the carb body. Notice also that the plug at the bottom of the bowl is drilled for safety wiring.



Side view shows idle-air screw on the left, near the bellmouth. Just above Mr. Iso's graffito is a blank boss where the throttle-stop screw would normally be. This carb doesn't have one and therefore depends on adjustment of the throttle cable to limit slide travel downwards. Some road-racing carbs do have the throttle-stop screw. This carb is spigot-mounted to the engine, rather than flange-mounted.



This starting-choke plunger is pulled up by a cable to provide starting enrichment. The cable is not shown but, if it were, the end fitting of the cable would fit into the hole at the top of the plunger and the action of the spring would hold the mechanism closed, or "off."



The parts in the attic are about the same as other Mikunis.

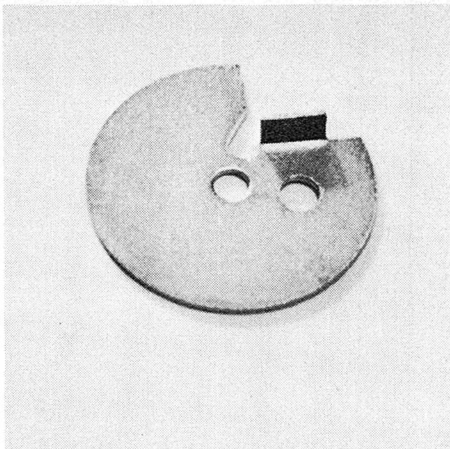
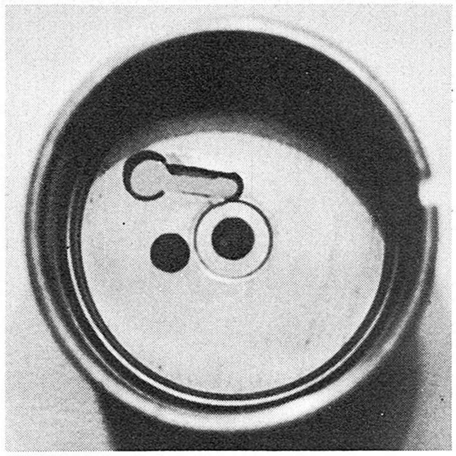
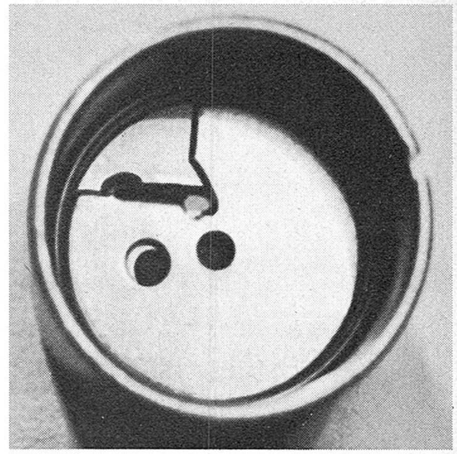


Plate which fits down on the top of the carburetor slide.

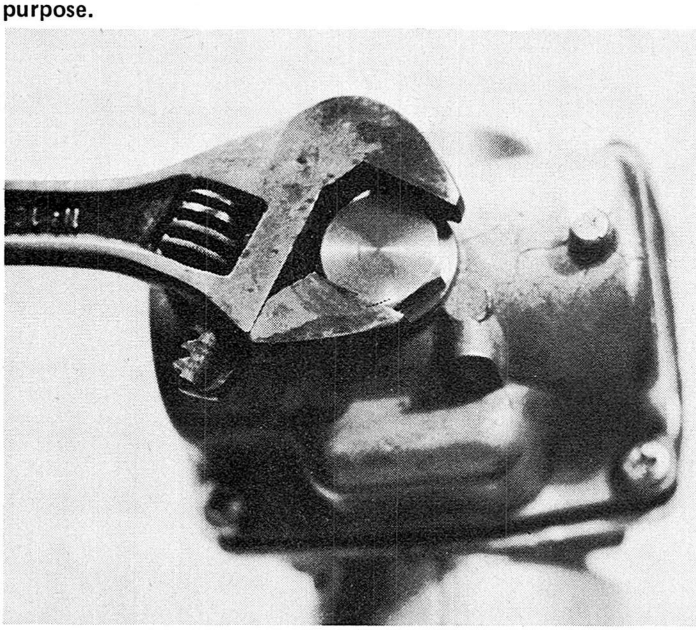


Slide, looking down into it from the top. Notice the key-hole-shaped groove for installation of the control cable.

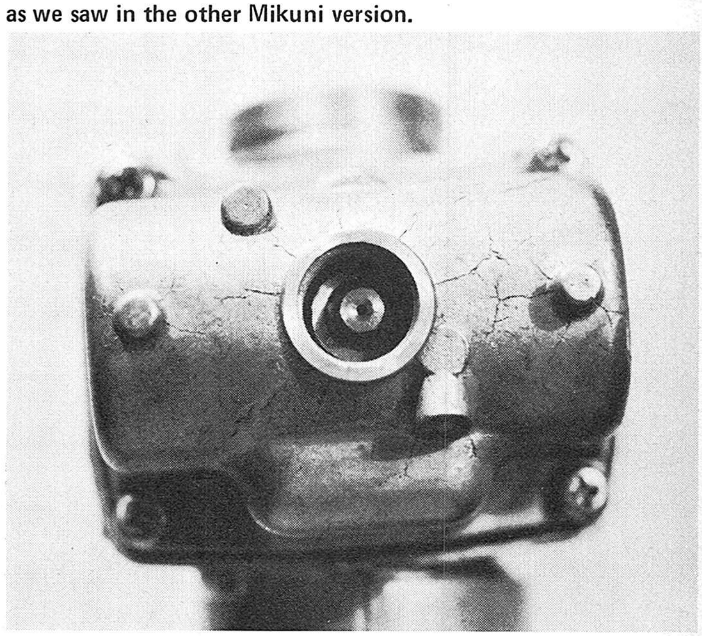


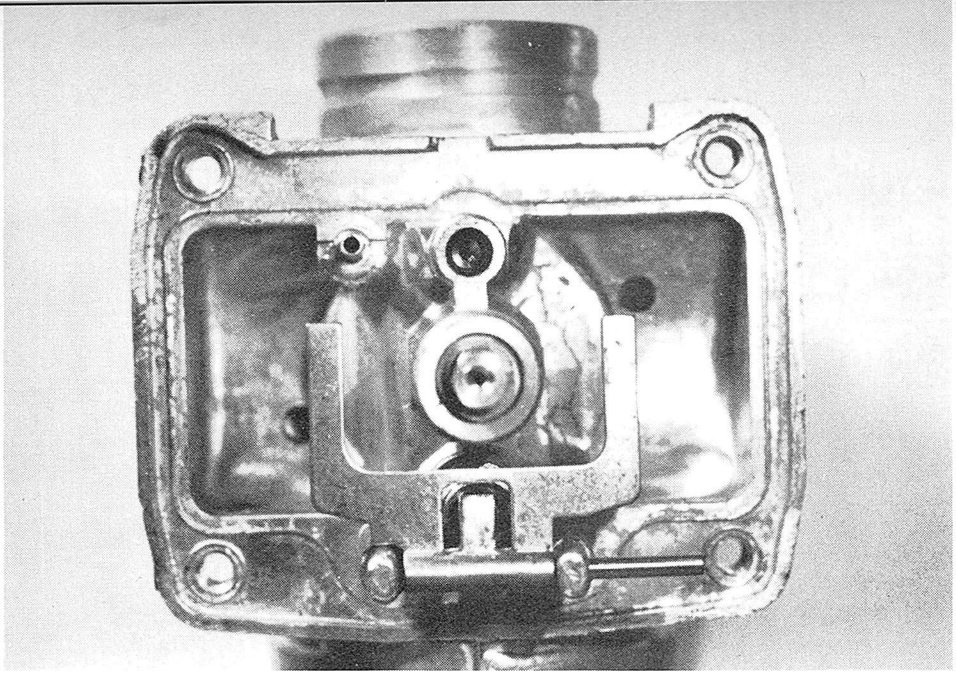
And here's how the plate goes. The tab fits down into the key-hole groove and prevents the control cable from getting back out after it has been properly installed.

Precision tool being used to remove the plug from the bottom of the float bowl. Lots of carburetors have a drain plug in the bowl and this can be used for that purpose.

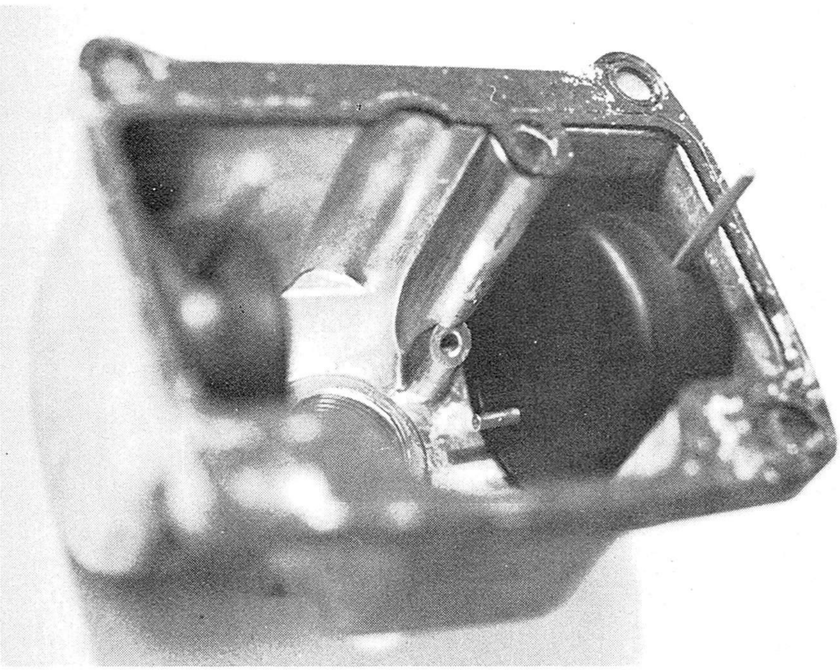


The main reason for the plug in the float bowl is to expose the main jet. Because this carb is spigot-mounted, that is clamped to the engine, the clamp can be loosened and the carb can be rotated so that the bottom is accessible. Then, by removing the plug, the main jet can be changed conveniently without any O-ring trickery such as we saw in the other Mikuni version.

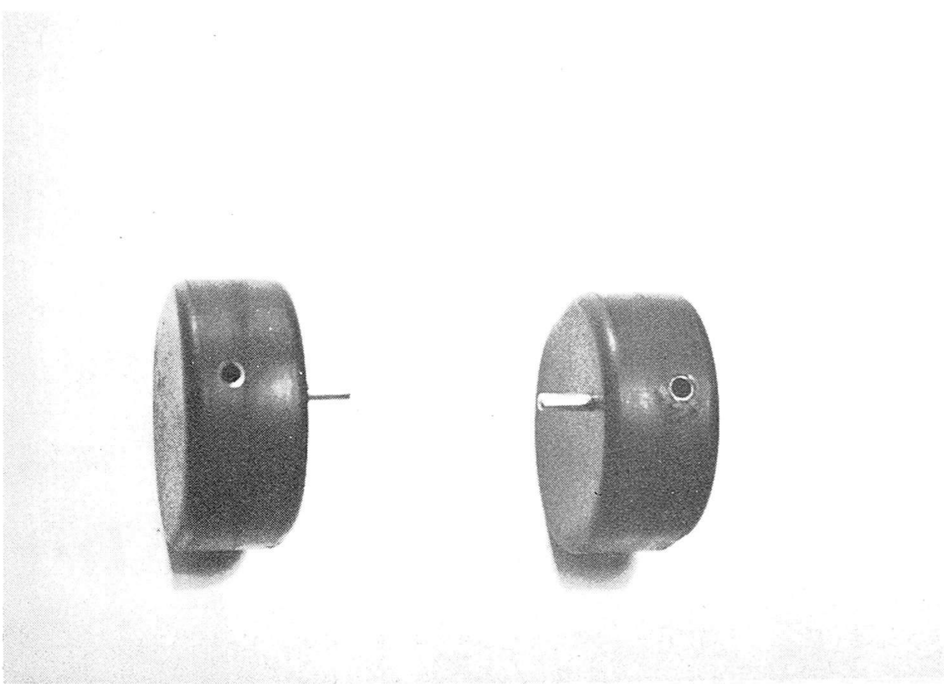




With the float bowl removed, we can look up at the bottom of the carb body. The float-needle lever does not have the floats attached. It is hinged in the conventional way and the hinge pin is shown partly removed. The tab on the float lever can be bent as needed to set float level. Main jet is in the center and the idle jet is down in the hole above the main jet. To the left of the idle jet is a tube which ducts fuel up to the starting-choke system.



The starting-choke tube fits down into a well, cast into the side of the bowl, so that it extends below the level of fuel. The well is fed from the orifice at the bottom. The two floats are independent of each other; each travels up and down on a rod and each has a pin sticking out the side which operates the float lever.

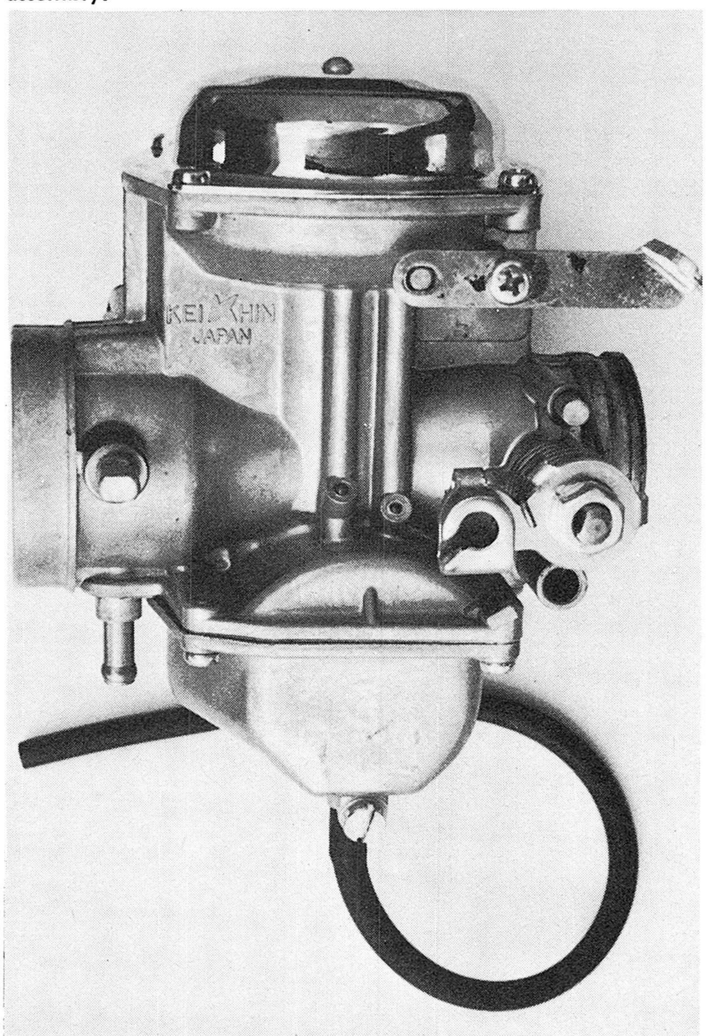


The floats look like this. Some models of this carb come with a more conventional float arrangement. The exact arrangement doesn't matter much as long as it controls fuel level.

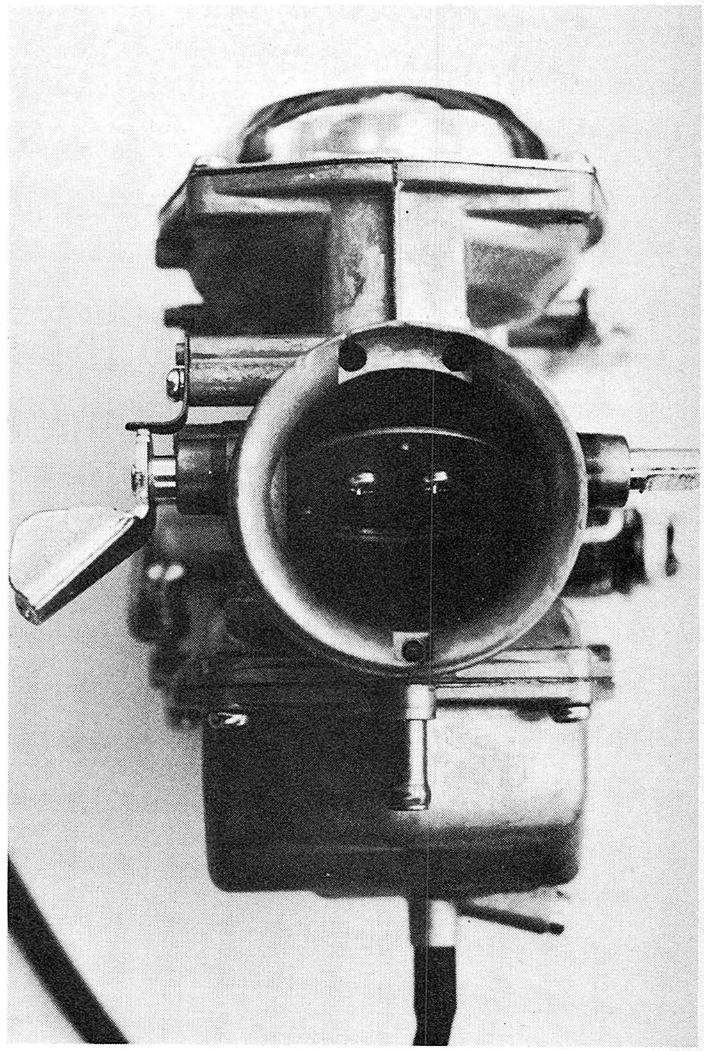
Kei-Hin As Used On Honda

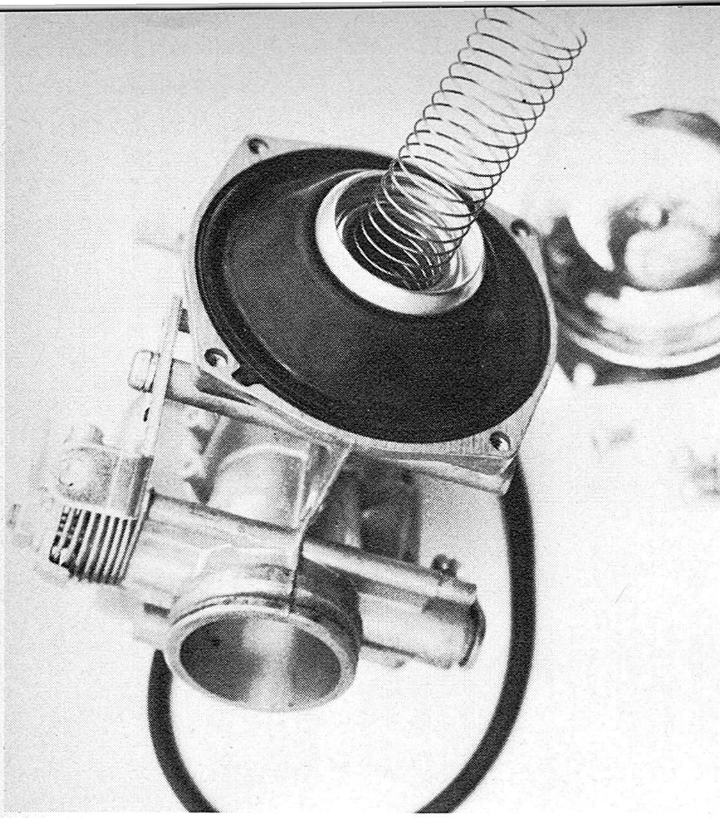
KEI-HIN CV CARBURETOR

The Constant Velocity (or Constant Vacuum) Kei-Hin carb is used on the Honda 450. Rubber hose on the bottom is part of the overflow outlet. The screw beside it is a float bowl drain plug. Fuel enters through the fitting which points downwards, just below the air inlet, makes a U-turn, and enters the float chamber through the needle valve. The throttle plate is controlled by the lever with a cable fitting on the end, at the right-hand side of the photo. Bracket above the throttle lever supports the cable assembly.

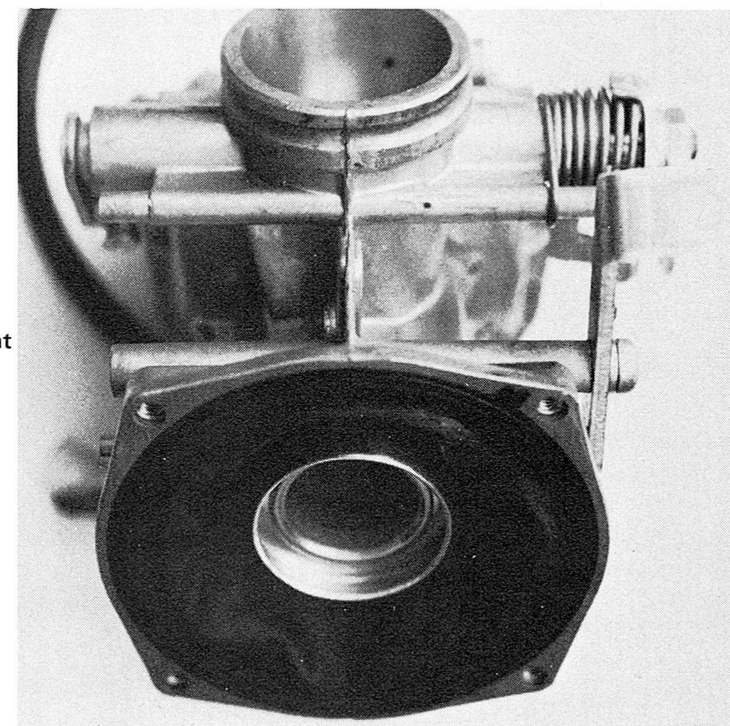


Inlet side of carb shows the choke plate and control lever.

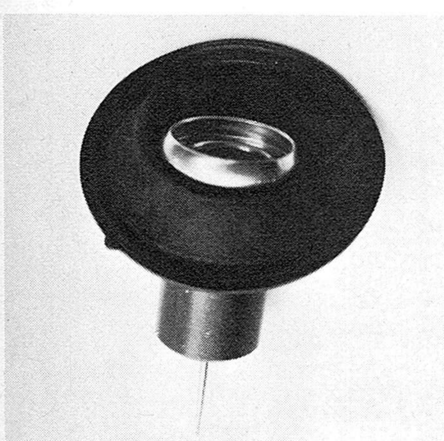




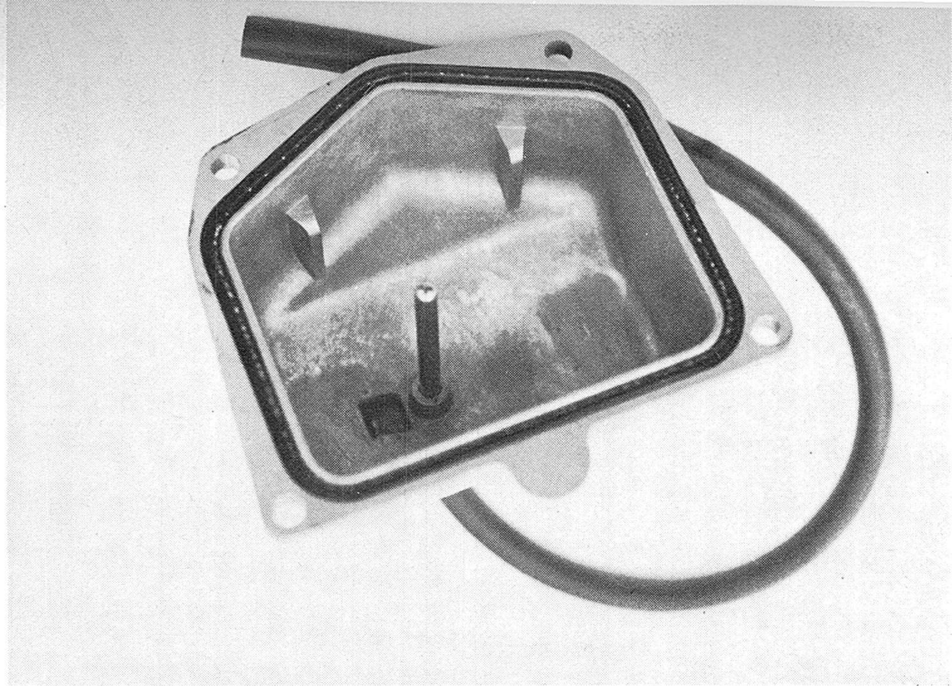
With the lid off, a fairly weak spring pops up out of the piston. As described in the text, this spring augments the weight of the piston in regulating slide position. The "vacuum" seal between the sliding piston and the upper chamber is created by the black flexible diaphragm whose outer rim fits into a groove in the carb body.



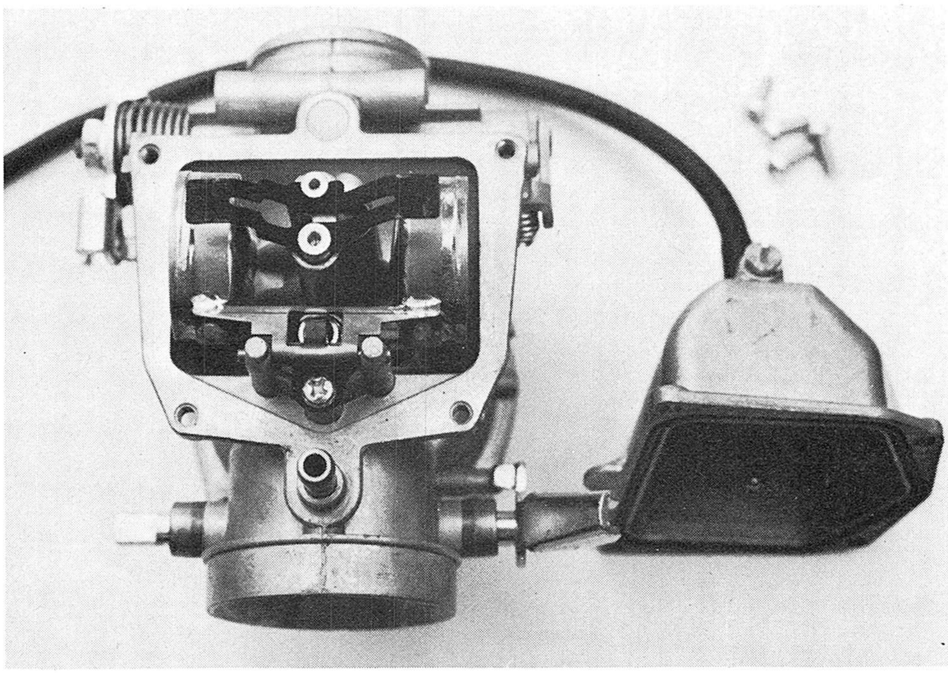
The diaphragm allows a surprising amount of slide travel, as of course it has to do. Here it is pushed all the way down.



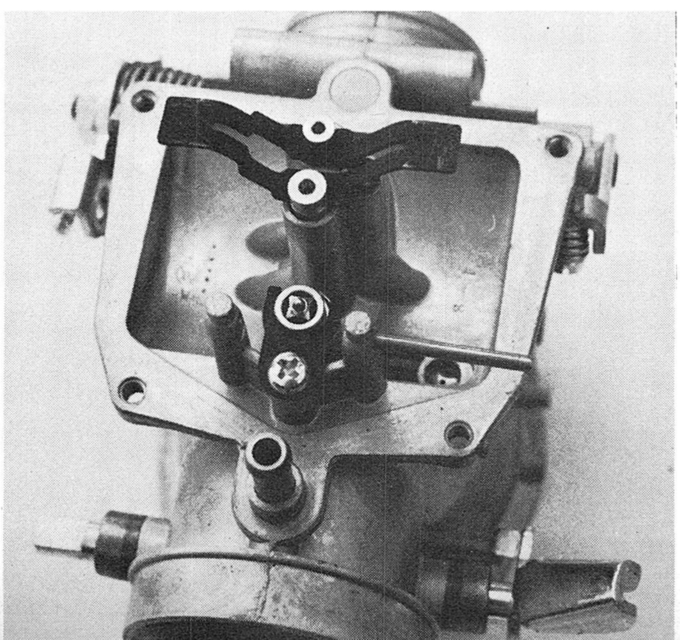
The carburetor slide and diaphragm come out as a unit. The needle is held in the bottom of the slide by a clip.



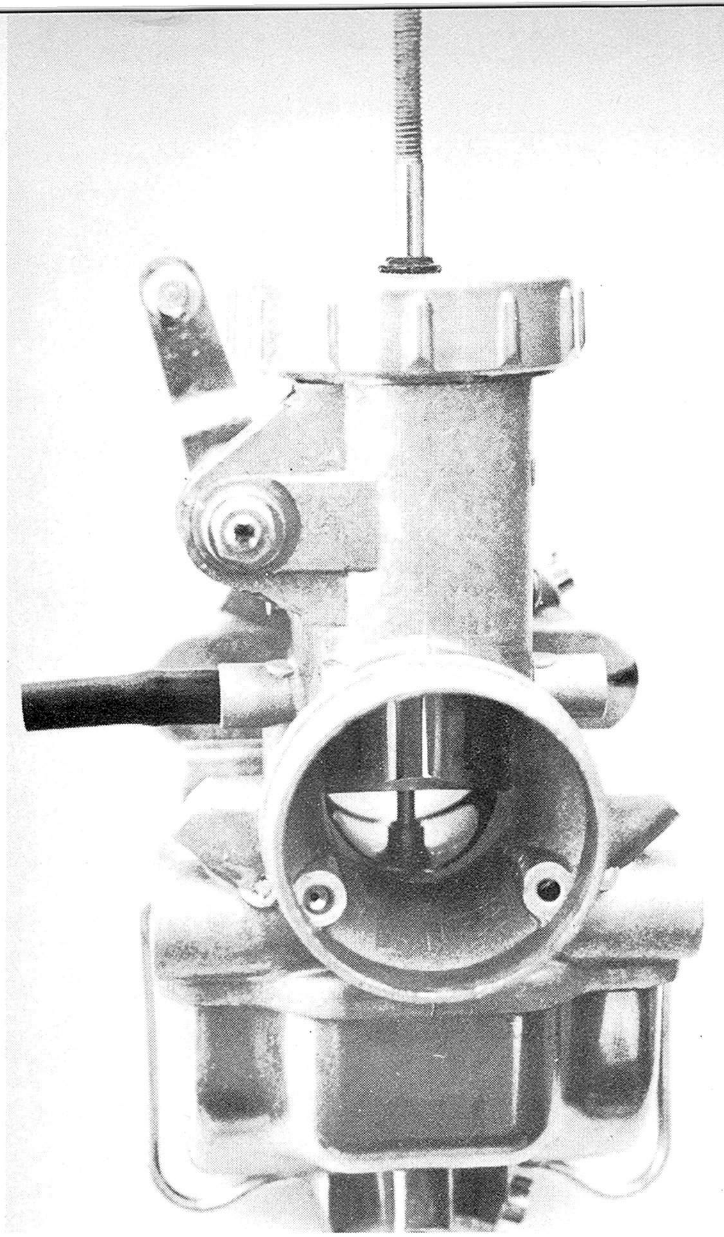
The float bowl is sealed to the body by an O-ring in a groove, which is a lot more convenient than a loose gasket and usually works better. The standpipe is the overflow. The channel in the bottom is for the drain plug.



With the float-bowl cover removed, you see a conventional float and needle assembly and an unconventional jet arrangement.



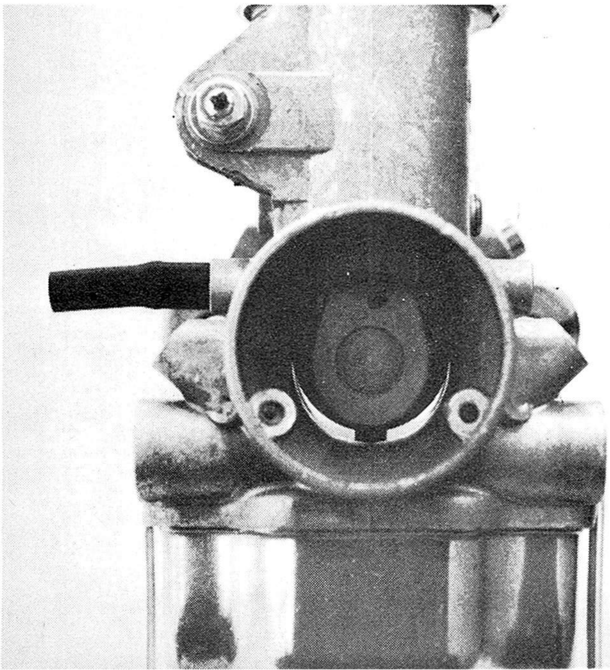
Main jet and slow-running jet are round, without a screwdriver slot or any obvious way to remove them. They are simply a slip fit into their passages. Each jet has a groove in it and the black spring clip fits into the grooves. When the float bowl is in place, the "feet" of the spring clip rest on the bottom of the bowl, exerting some upward pressure to hold the jets in place. This is a clever arrangement. Jets occasionally vibrate loose, when screwed into place. I don't see any way these jets can come out accidentally.



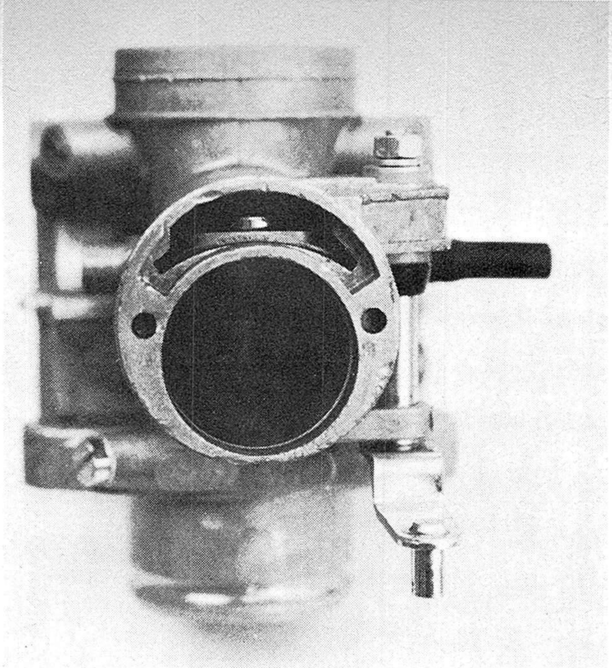
KEI-HIN "PUSH-PULL" CARBURETOR AS USED ON HONDA

Most motorcycle carbs depend on a spring above the slide to close the throttle. Sometimes this doesn't work due perhaps to a small speck of dirt in the throttle-slide cavity. This carburetor which I call a "push-pull" type provides for positive mechanical control of the slide position in both directions. The slide is attached to the threaded rod extending out the top of the body. The lever on the side, near the top, operates a starting choke shown in a following picture.

Notice the complete architectural symmetry of the casting, except for the choke lever. This allows this unit to be manufactured as a left-hand or a right-hand model using the same basic casting and drilling out or plugging orifices as needed.

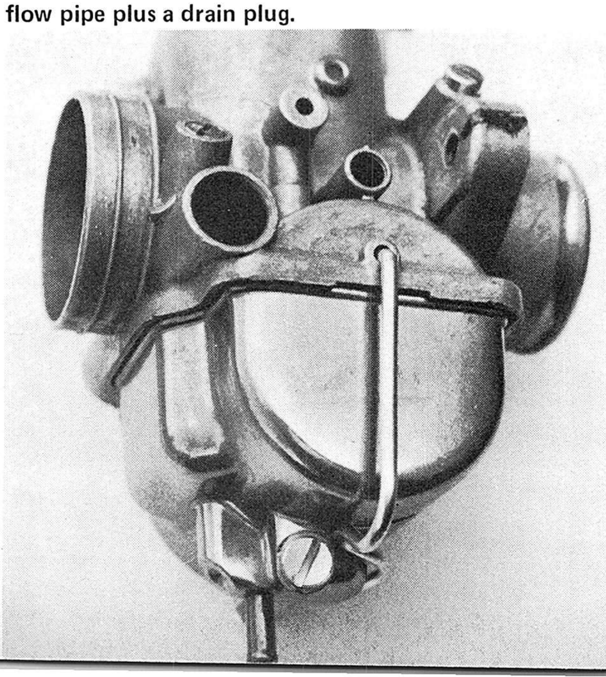


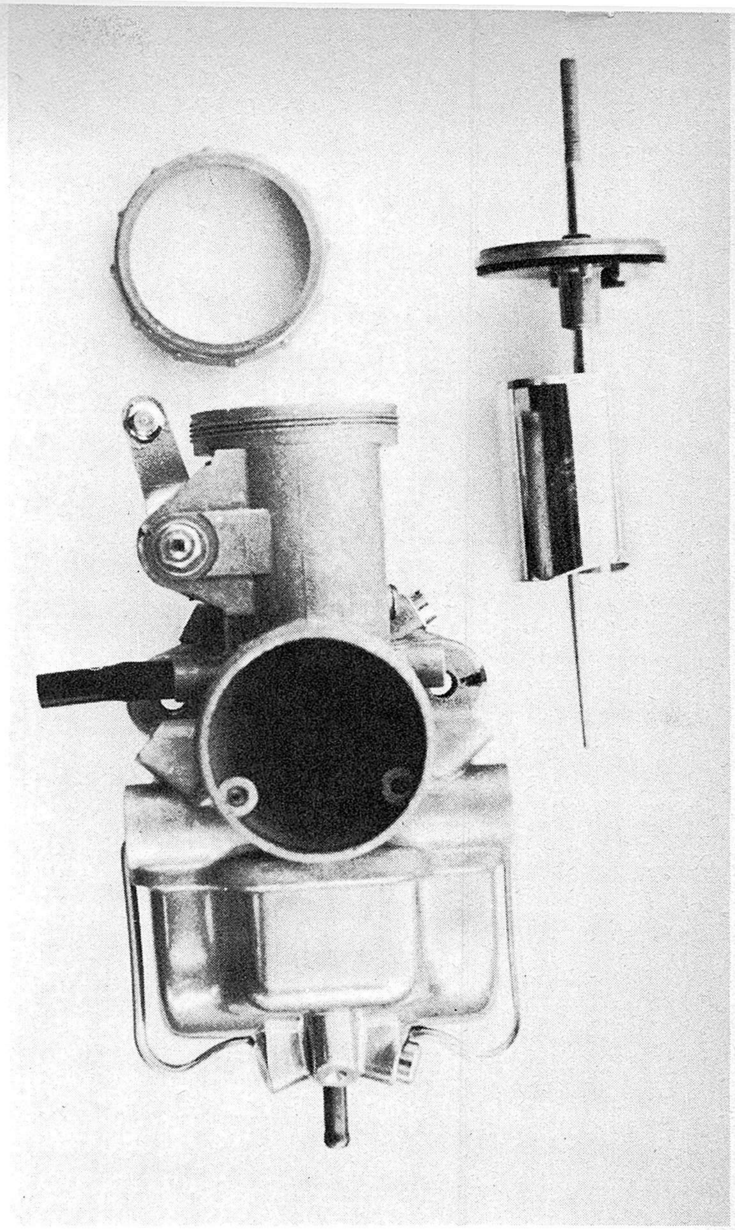
When the choke lever is operated, a linkage pushes down the choke plate, in front of the throttle slide. The circular disc in the center of the choke is spring loaded and can be pulled open by engine vacuum when the choke is fully operated.



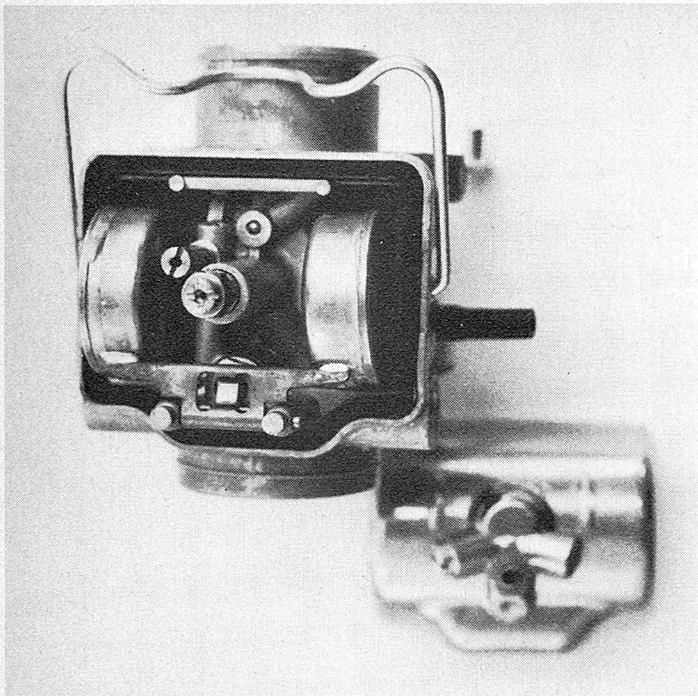
The starting-choke assembly moves up and down in the curved cavity in front of the throttle-slide bore.

The float bowl is held in place by a wire bail, rather than screws and has an overflow pipe plus a drain plug.



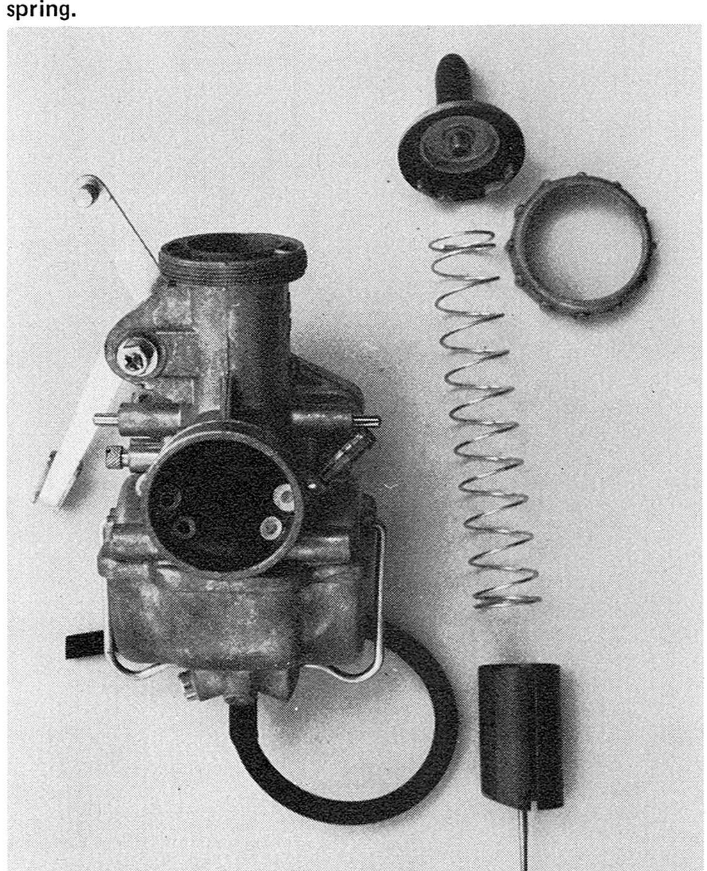


With the top ring removed, the top plate and slide assembly can be pulled out. The operating rod is firmly attached to the slide and passes through a hole in the top plate. An external lever is attached to the rod to move the slide up and down. This carb is used on multiple-cylinder engines, one per cylinder, and consequently the operating levers are ganged on a shaft so they all go up and down together. This mechanism is part of the motorcycle rather than part of the carburetor. Some versions of this carb have an elongated housing on top which contains the throttle operating lever. The push-pull operation is achieved by two cables connected to the twist-grip and the arrangement is shown in Honda owner's manuals and shop manuals.



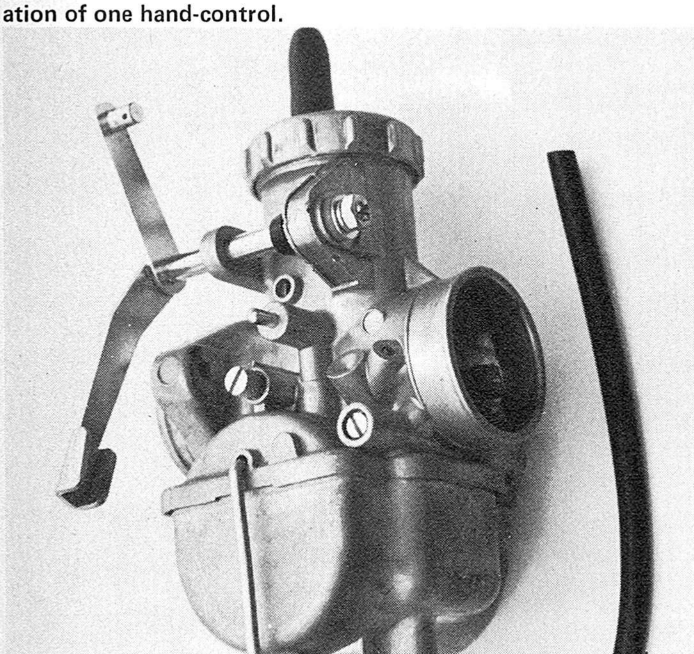
When the bail is flipped aside, the float bowl can be removed, exposing conventional floats and jets.

The throttle slide is pulled up by the control cable and returned by the internal spring.



CABLE-OPERATED KEI-HIN

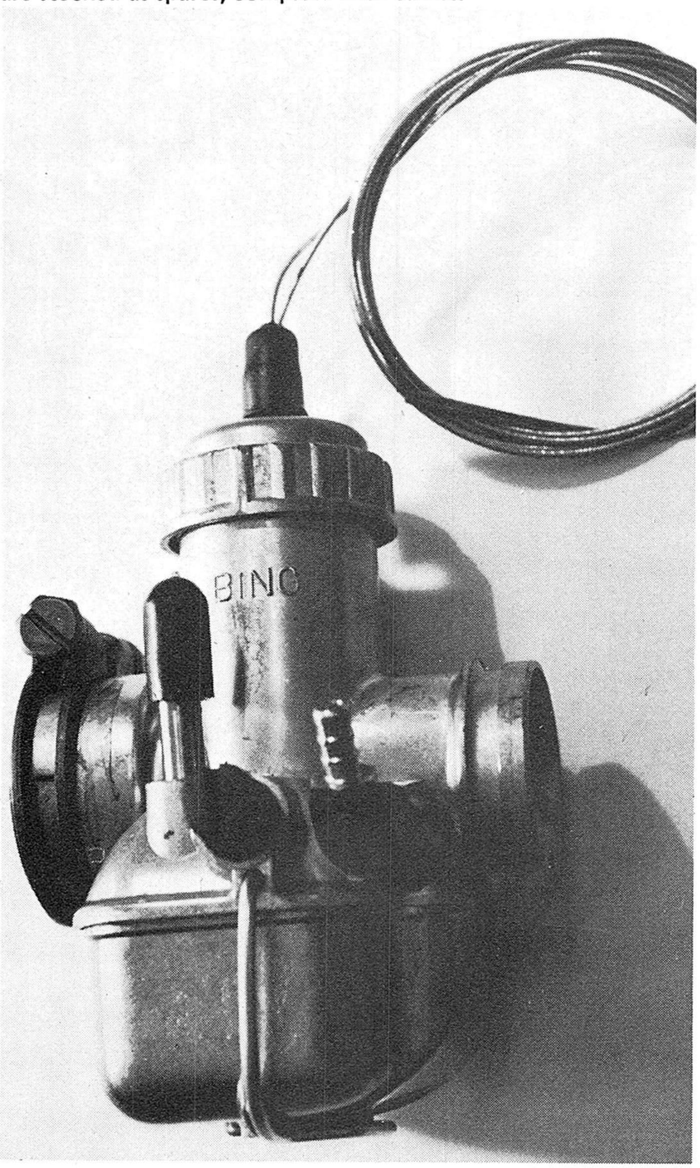
After seeing the other Kei-Hins, there aren't many surprises here. This carb has the same starting-choke as the one shown previously. The "bell crank" arrangement allows two carburetors to be coupled together so that both can be choked by operation of one hand-control.



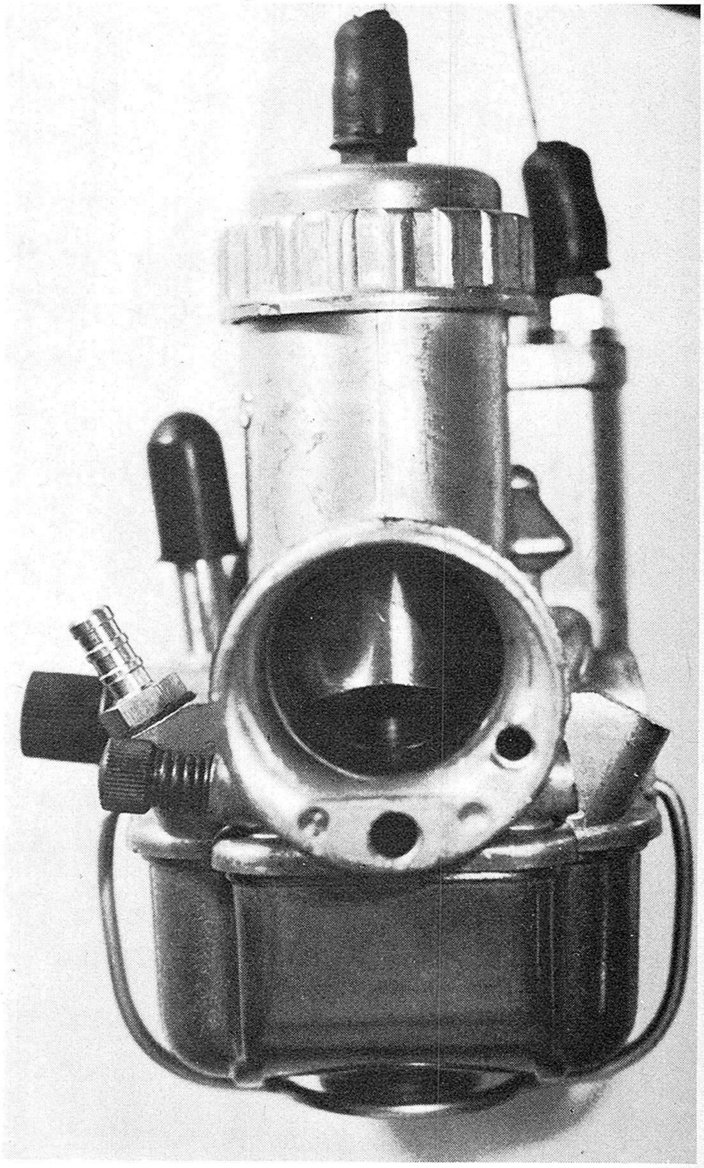
Bing

Bing carbs are used on several makes of motorcycles from Northern Europe. They make the CV type used on BMW and the conventional carbs found on Sachs and other engines. These photos are of the conventional type.

This Bing is spigot-mounted to the engine and coupled to the air cleaner by a hose clamped around the inlet bell. By loosening both clamps, the carb can be rotated which is a great convenience when changing jets or needle-clip position. This is how they are stocked as spares, complete with cables.

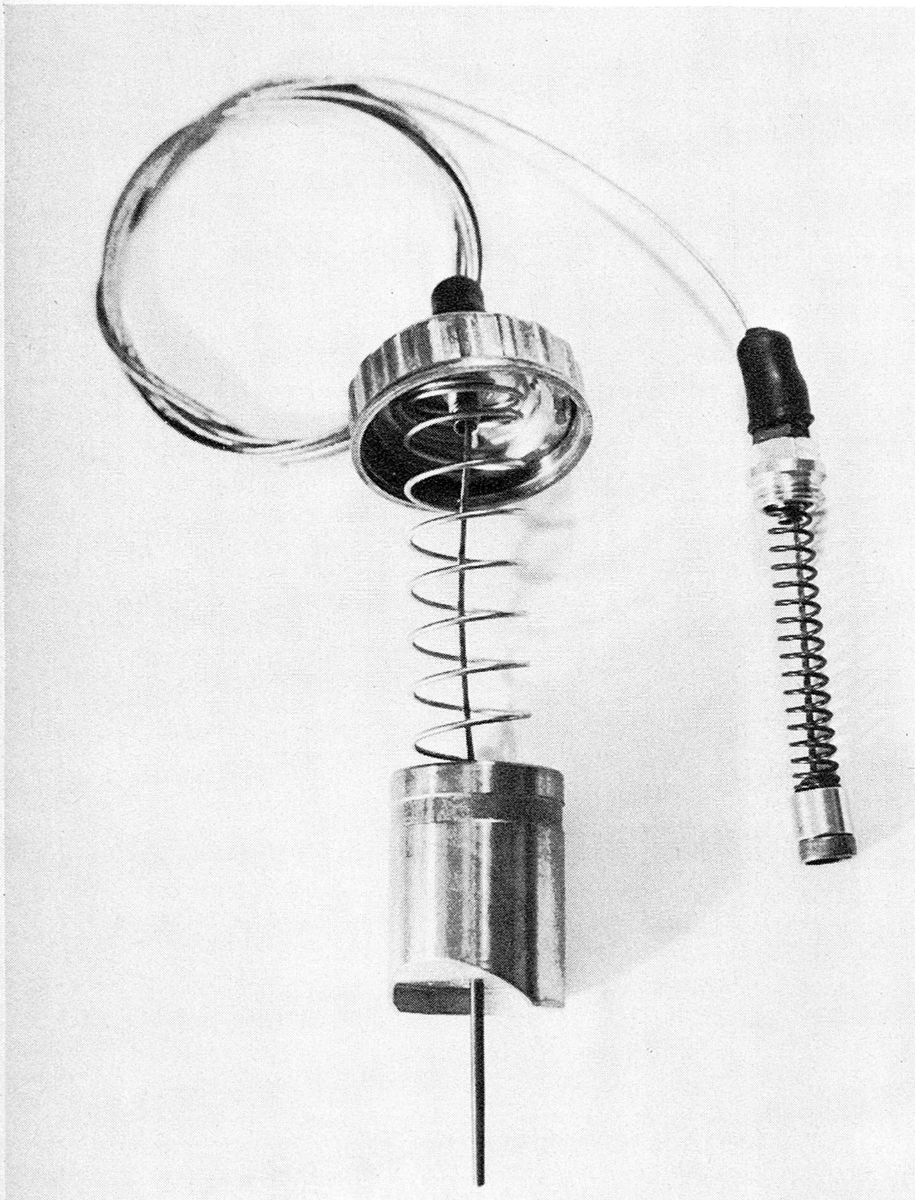


With typical Teutonic thoroughness, this Bing has both a tickler and a starting carburetor. The tickler is the plastic-topped plunger on the left and the starting carb is at the far right rear. The knurled knobs at the left are throttle-stop screw and idle-air screw. Fuel inlet fitting is between them.

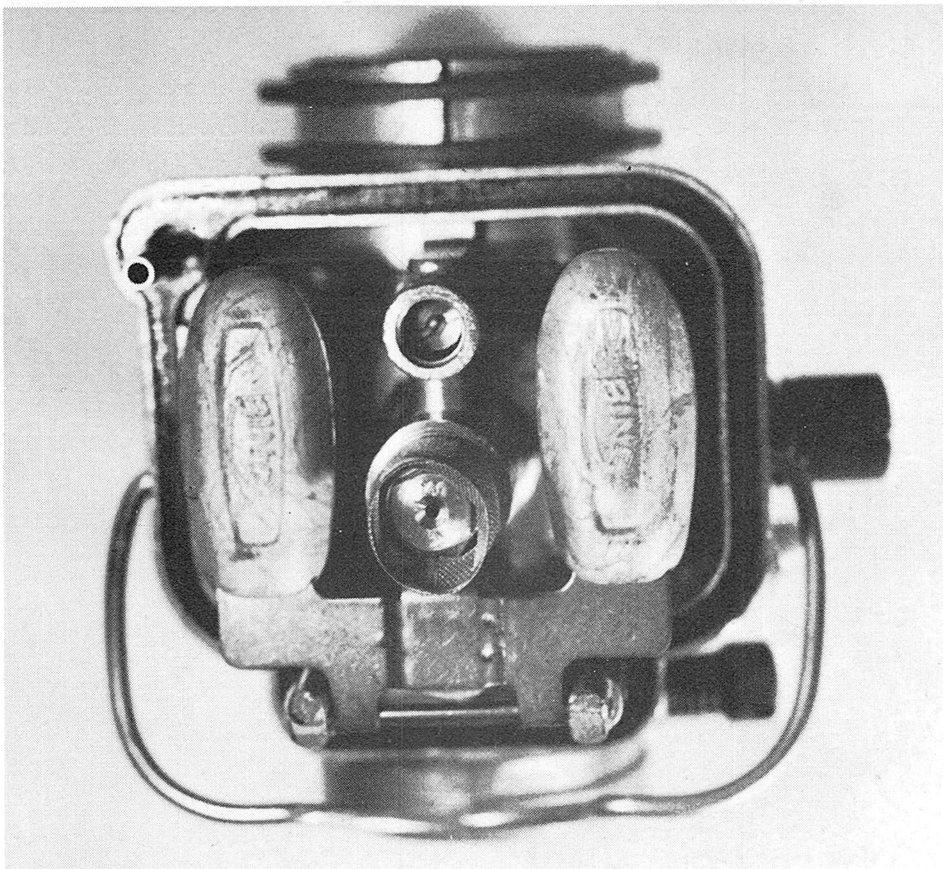


NOTE: For the photos in this section I borrowed a random selection of carburetors from a random selection of dealers in Albuquerque. For trusting me to get them back together again in proper order, I thank:

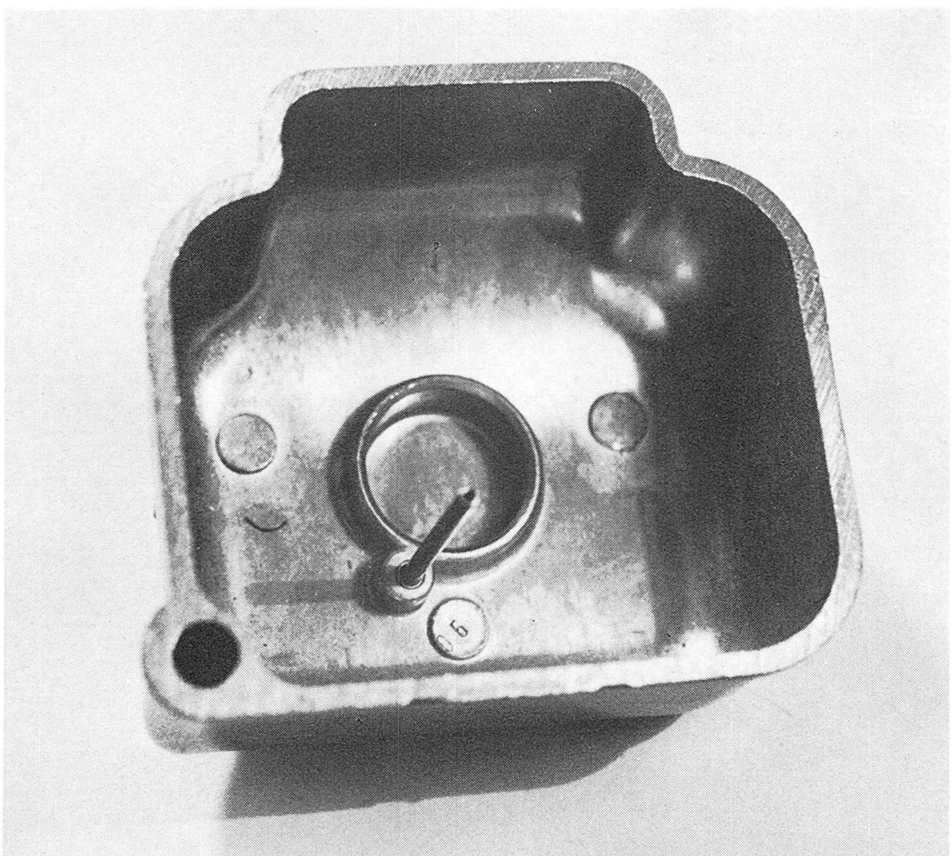
David Spain of Bobby J's Yamaha
Bob Morgan of Bob's Motocross and Kart Shop
Mike Ryan of Simonson Honda
Harold Goldberg of Weird Harold's Cycle Center.



Throttle-slide assembly and starting-choke assembly with their cables intertwined. This starting choke works so well that it is commonly used as a way to stop the engine, instead of a kill button or switch. When you want to stop the engine, you operate the "starting lever" on the handlebar which floods the engine so it quits running. Flooding is not a good way to kill an engine. On a four-stroke it washes oil off the cylinder wall and you may get scuffing when the engine is started next time. On a two-stroke excess fuel may cause hot-start problems. *I recommend installation of a kill button anyway.*



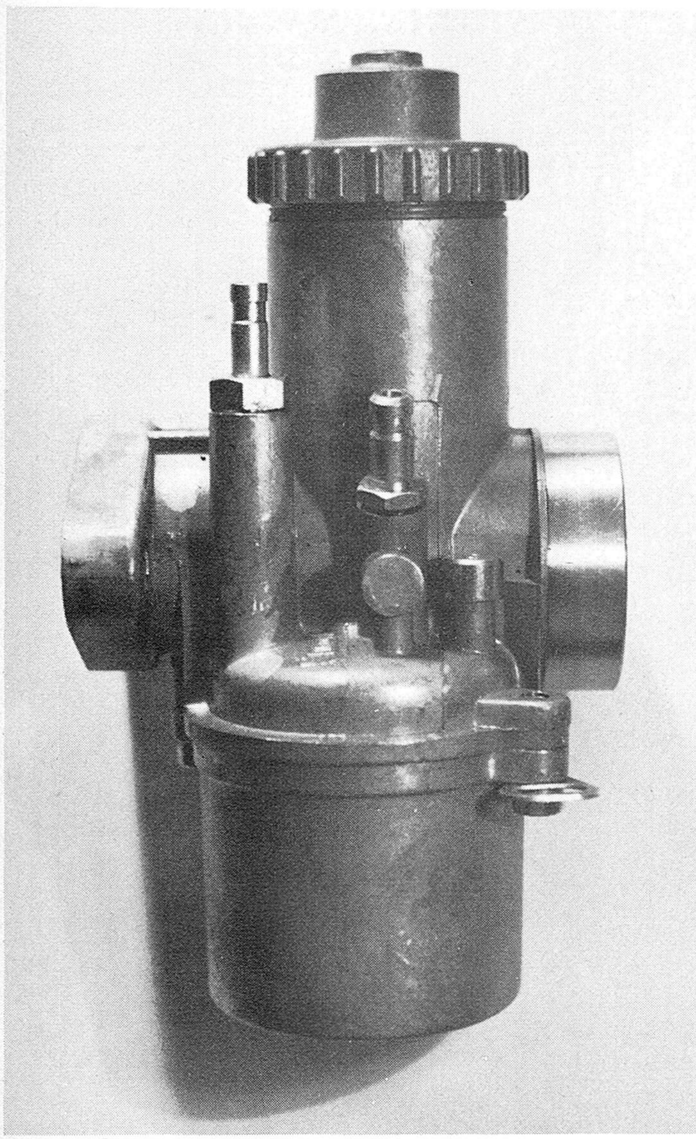
With the float bowl removed, you see the main jet, the idle jet, and solid plastic floats. These floats are made of a light-weight rigid plastic foam, with closed pores, impermeable to gasoline. There is no way these can spring a leak, fill up with gasoline, and change your float level. Surrounding the main jet is a wire-mesh ring which has been crumpled during original factory assembly. This seems to be normal and is no cause for worry. This part looks like a fuel strainer but its main purpose is to hold a reservoir of fuel around the main jet. Without it, the main jet can "suck air" when fuel in the bowl is sloshed around due to bumps and jumps. *Don't remove this ring.* The tube in the corner draws fuel for the starting carburetor from a well in the float bowl.



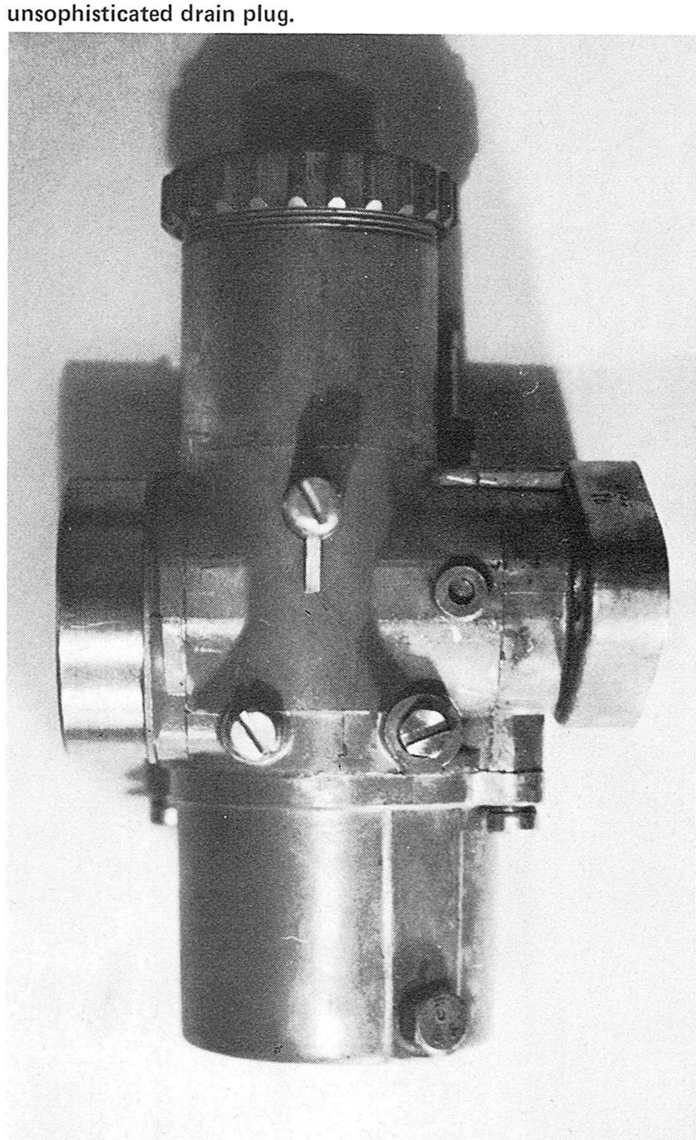
Interior of float bowl shows a depression in the center which captures the open end of the wire-mesh screen around the main jet. The standpipe is an overflow. The well for starting-carburetor fuel supply is in the corner.

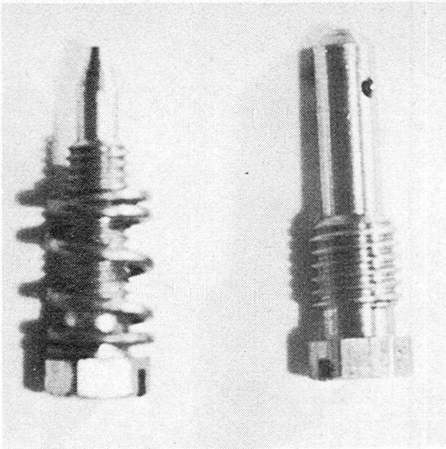
Jikov

This Jikov is flange-mounted. Nearest the flange, the hose-fitting is the float-bowl vent. A hose from here goes up under the seat and into the air cleaner housing. If the cable entry is sealed and everything else is tight, this carb can run submerged in water with no problem. Fuel entry is in the center and the squat little button at the right is the tickler.

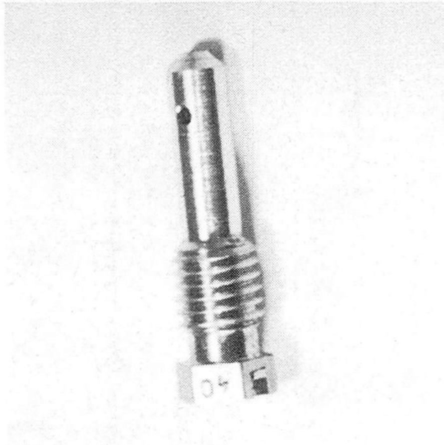


Right-side view shows three slotted screws in a triangle. The one on top is the throttle-stop screw. Lower left is the idle-air screw. Lower right is, believe it or not, an externally changeable idle jet. (They call it a slow-running jet.) At the bottom is a very unsophisticated drain plug.





Idle-air screw, at left, is conventional. The other screw could be mistaken for a fuel adjustment but it is a jet. The blunt end is plugged into a hole in the carb body casting.

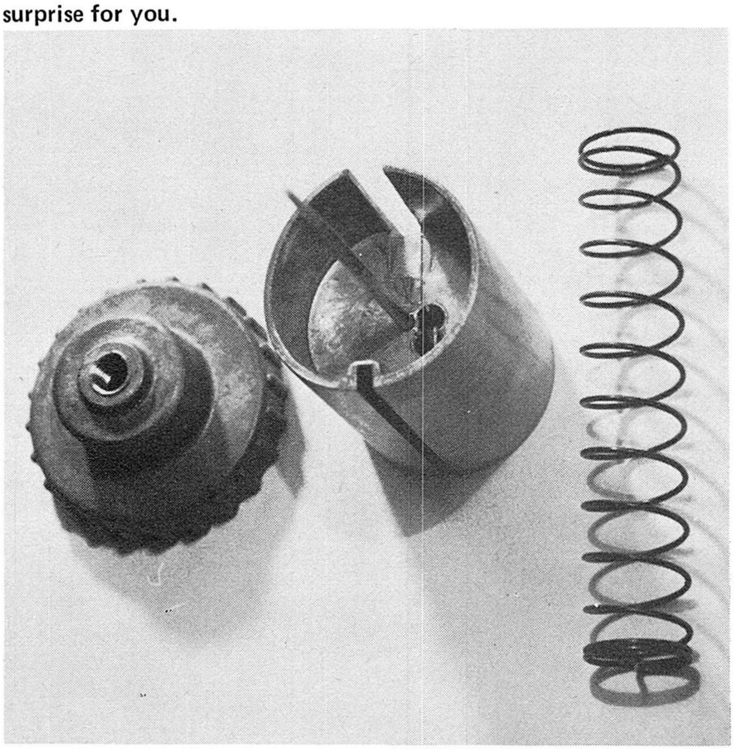


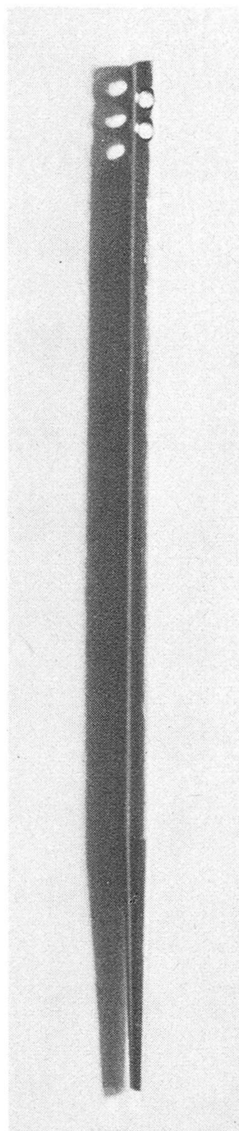
Closer view of the idle, or slow-running jet. Obviously, it's a 40. The logic of making this jet accessible but burying the main jet escapes me, however *any* accessible jets are better than none.

Jikov carburetors—come on CZ bikes and also Jawa, I suppose, although I have never looked closely at a Jawa. The honored custom among CZ owners in the U.S. is to discard the Jikov and install a Mikuni or some other more common instrument. I have a sneaky suspicion that this is another fad and that, properly tuned, the Jikov should be a satisfactory carburetor. However I have never tuned one.

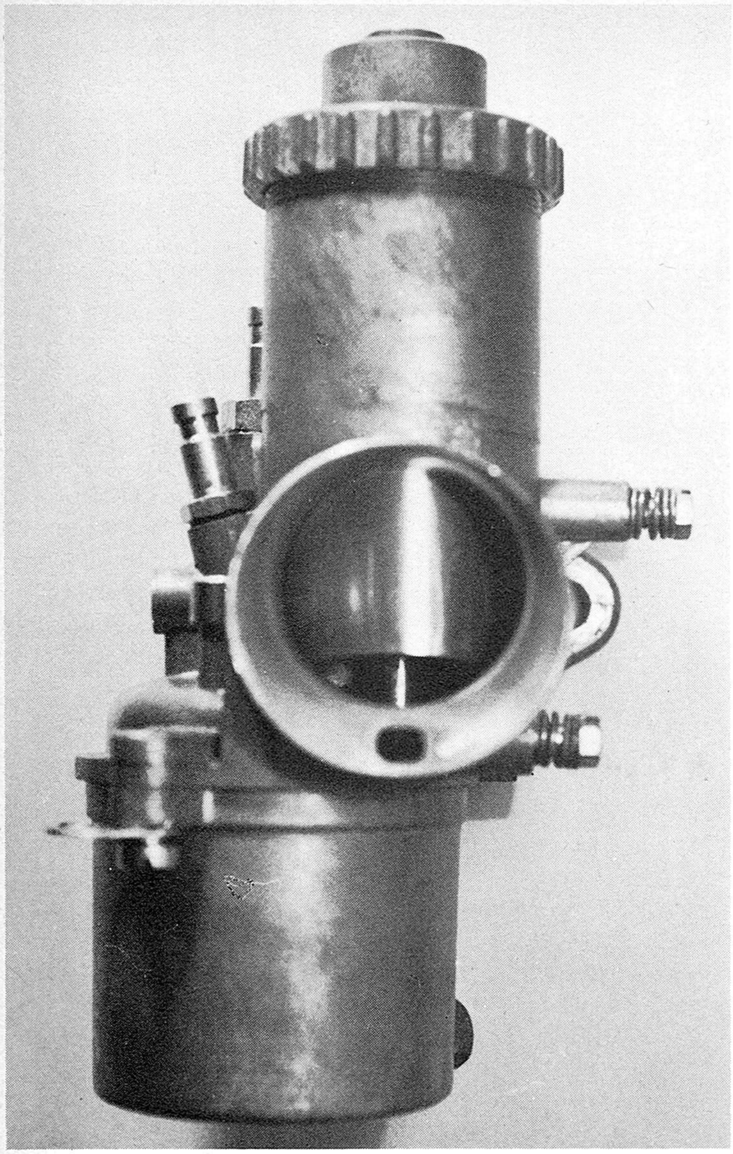
Among all the other carburetors shown in this book there is so much similarity that you begin to wonder who copied who. Not so with the Jikov. It's an interesting carb to take apart, to see another way of doing almost everything.

Top cover, slide, and spring. Look carefully at the shadow made by the spring and you will see that, at one end, the wire is bent so as to stick straight across the open end of the spring. We will call this straight piece of wire a tang. It may hold a little surprise for you.



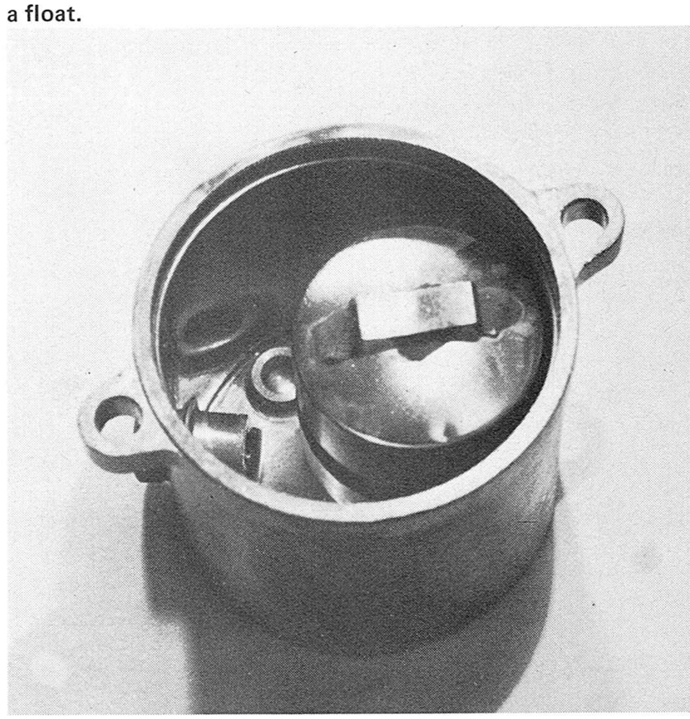


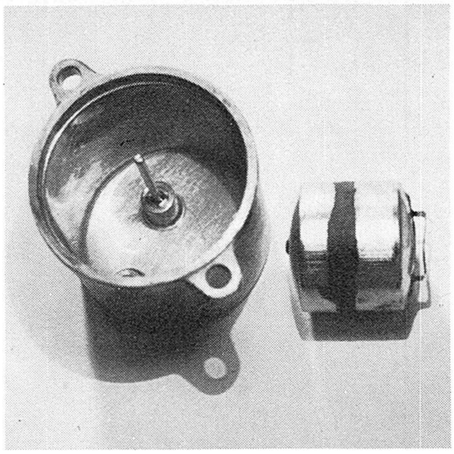
This is the needle. Two holes are visible in direct view and three more (drilled at right angles) are visible in the shadow. The five holes are for position adjustment.
How do you suppose the needle is held in place? One of the holes is slid over the tang on the bottom of the spring. That's it! No clips to break or lose, no fancy washers or plates to hold everything together. Stone-simple and, as I see it, foolproof.
There is genius in doing something in the most utterly simple way and there is usually a big payoff in reliability as a result. We are seeing the handiwork of some unsung Czechoslovakian genius here.



Front view is also a bit startling. The float bowl is offset to allow for the primitive float arrangement which you will see in a minute. The throttle-stop screw seems unusually high in the body of the carb; the groove in the slide is also unusually long. The shape of the air-bell is clean looking and there is only one opening. It admits bleed air to the needle jet and also provides idle air, regulated by the adjacent idle-air screw.

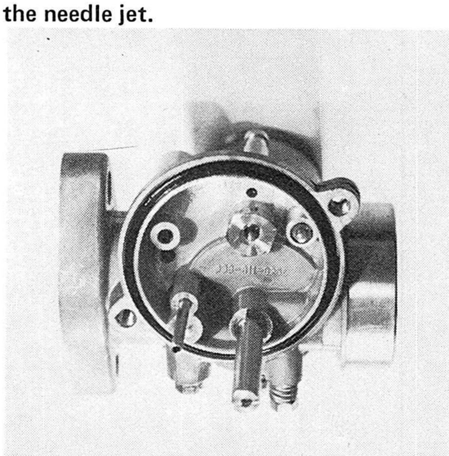
Drop the bowl and there's some kind of a float.





The float is metal, made in two halves soldered together, with a tube through the center. It slides up and down on the rod fastened in the bottom of the bowl. The bridge across the top of the float operates the needle-valve and may be bent up or down a little in order to adjust float level. I am not overwhelmed with admiration of this float design.

The bottom of the main casting shows the rest of it. The hole at top left leads to the vent. Next to it is the float needle. At top right is the tickler. Small tube at bottom left picks up fuel for the idle system and delivers it to the externally attached slow-running jet. The large tube holds the main jet at the bottom and is the fuel passage to the needle jet.



As you remember—from the section on carb theory, the float bowl is normally vented to outside air pressure. Air flow through the venturi causes reduced pressure in the bore of the carb. Fuel flows from the float bowl into the main air passage due to this pressure differential—that is, the difference between outside air pressure admitted to the float bowl and the lower pressure in the venturi.

Because the air filter offers some opposition to air flow, there is a pressure drop across it and the pressure on the "downstream" side of an air cleaner will always be less than that of outside air. When you tune your carburetor with a clean air filter, you automatically compensate for the reduced pressure of the air coming into the venturi due to the presence of the air cleaner.

As the air filter gets plugged up with dirt, two things happen. It passes a smaller volume of air and causes a higher pressure drop across the filter. If the fuel bowl actually is vented to outside air, it remains at outside air pressure no matter how dirty the air cleaner gets. The result is that more fuel is drawn into the engine on account of the extra pressure drop in the carb venturi caused by the dirty air filter. If you clean your air filter before it gets really bad, this is not a serious problem.

Even though an outside air vent to the float bowl is necessary on carburetors, you will rarely see it pointed out on carb drawings with a name and part number. Nor has this book called attention to it except in the theory sections, and right here. Air venting is usually accomplished as an incidental result of providing an overflow. When there is a passage which allows fuel to escape when the fuel is at a level higher than normal, then that passage will normally connect outside air to inside air except when fuel is overflowing.

Theory suggests, and perfectionists agree, that the float bowl *air vent* should be connected by a tube into the air cleaner volume *behind* the filter. If so, then a dirty air filter would reduce both pressure in the venturi and pressure in the float bowl so the mixture would not get rich due to a plugged-up cleaner.

Obviously such a passage cannot also be an overflow because it doesn't make any sense to dump fuel out of the carburetor into the carburetor. Therefore, without some tricky arrangements which I haven't invented, you can't have both. If you vent the bowl to the interior of the air cleaner, you can't have an overflow provision. And vice versa. CZ does the first. Most others do the vice versa.

More incidental amazements while we are in the vicinity: The orifices for bleed- and idle-air are inside the air cleaner. For the idle system, this is just to avoid sucking in dirty air. For the bleed system, this is to avoid that and also to avoid undue mixture enrichment when the filter gets dirty.

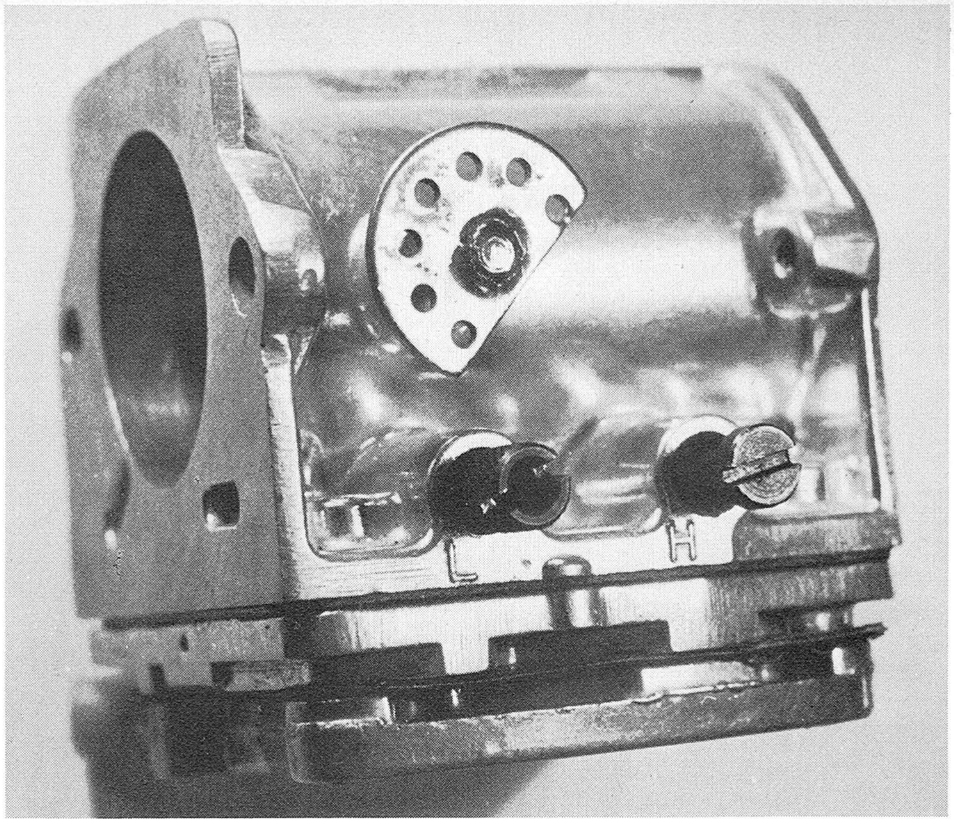
When I take apart my carburetor I *always* find some fine dirt particles in the bottom of the bowl. I use a good inline fuel filter which will stop particles this size, so I don't think they come in with the fuel. I think my air cleaner stops particles of this size also, but even if it didn't it's hard to imagine any way they could move against the flow of fuel and get down into the bowl while the engine is running.

I *think* this little bit of dirt is coming in through the overflow passage. As the fuel level changes in the bowl, I can imagine that outside air is pumped in and out of the air-space in the bowl, bringing in bits of dirt.

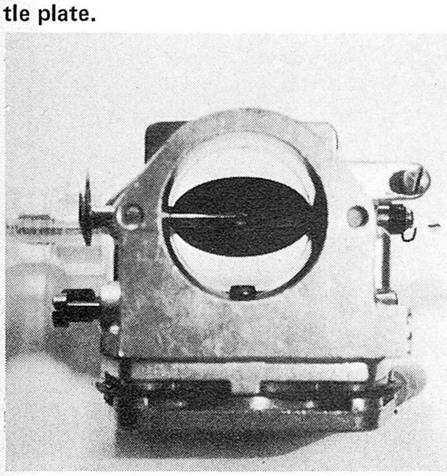
Pumper

Depending on how recently one of the magazines has effused about pumper carburetors, they rise and fall in favor among motorcycle engine modifiers. This type of carb was originally designed for applications such as chain saws which could not depend entirely on gravity feed of gasoline into the carburetor. They became common for go-kart engines because a famous chain saw maker also became a famous go-kart engine maker (McCulloch). From this base, they occasionally make a foray into motorcycle circles.

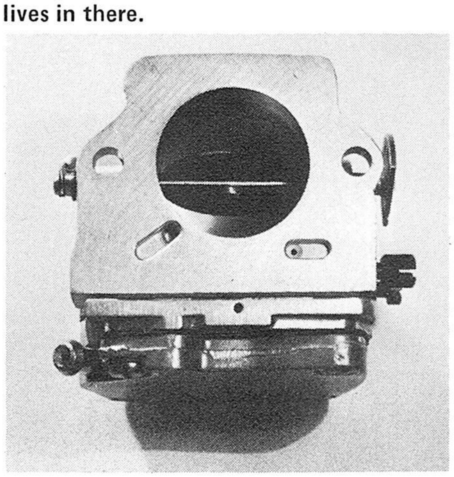
Basically, this is a simple plain-tube carburetor with a built-in fuel pump operated by vacuum-variations from the crankcase of a two-stroke engine. It uses a throttle-plate to regulate air flow and has two fuel orifices in the air passage through the carb. Fuel flow through these orifices is adjusted by the two external screws marked L and H, for low-speed and high-speed.



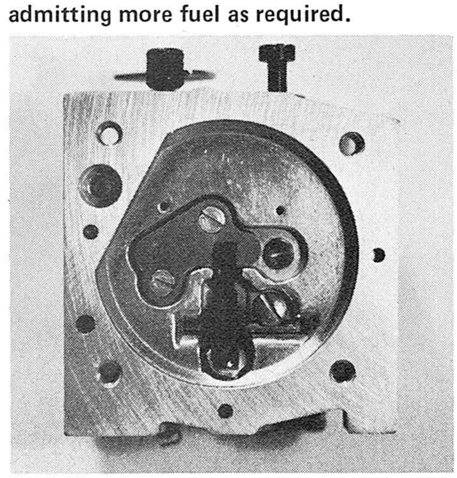
View from the inlet side. The visible orifice in the bore is the high-speed jet. The low-speed jet is simply a hole close to the throttle plate.

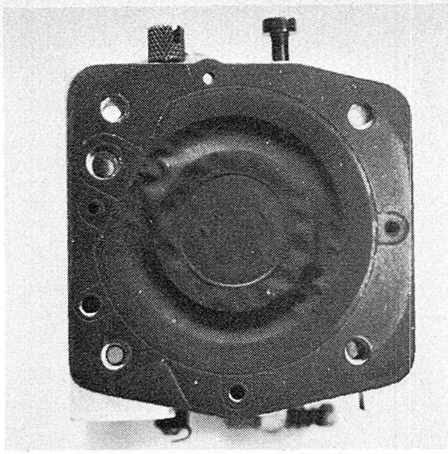


This side of the carb bolts to the engine. The holes in this face admit the pressure-variations from the crankcase in order to operate the fuel pump part of this instrument. Notice the several layers of "plates" bolted onto the bottom. The fuel pump lives in there.

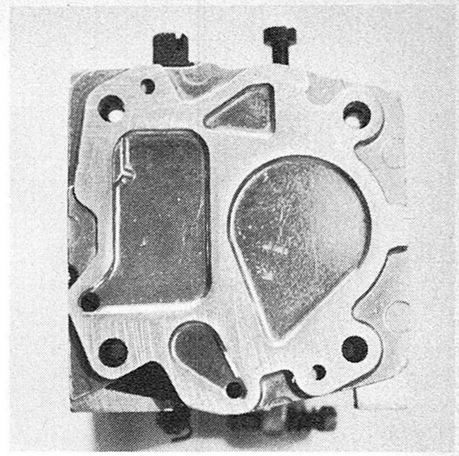


With all the plates removed, you can see the main cavity which contains fuel during operation. The two holes feed directly into the air passage through the carb and are the high- and low-speed orifices. The black lever is spring-loaded and operates a needle valve, admitting more fuel as required.



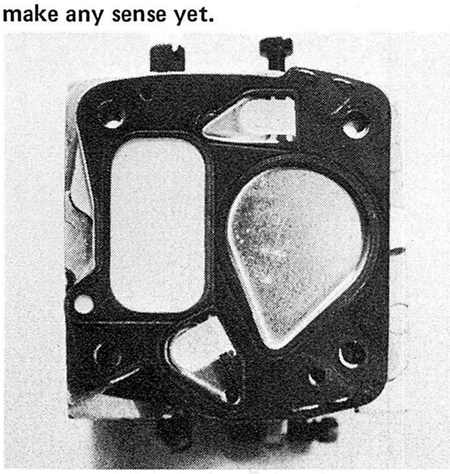


The next layer is this flexible diaphragm which has a solid center part to operate the needle-valve lever. The fuel is in the main cavity on the opposite side of this diaphragm. The small hole through the gasket at the bottom is the fuel passage up to the needle valve.



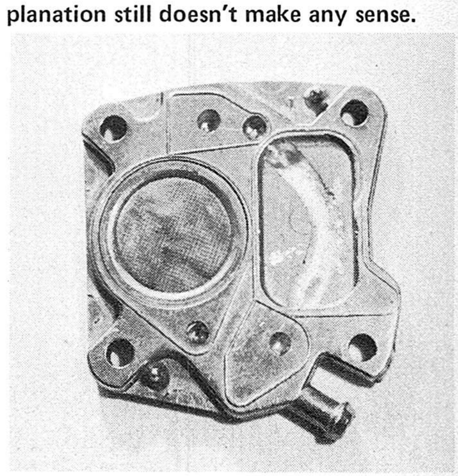
Next layer is this plate with a bunch of cavities in it.

Over the bunch of cavities fits this layer, made of gasket-like material sandwiched over some fabric things. The light-colored parts are the fabric things. There are three of them. The two U-shaped tabs are flapper valves. I know this explanation doesn't make any sense yet.



Bottom layer is this piece. The side shown is clamped up against the layer with the fabric inserts. Now I'll try to give you an idea of the fuel flow route although it helps a lot to hold the pieces in your hand while you figure it out.

From the fuel fitting, fuel gets over to the circular piece of wire mesh and flows through it to strain out impurities. Then the fuel goes through one of the one-way fabric flappers and into the rectangular cavity with the horseshoe-shaped groove. From this cavity it is urged out by pumping action past the second flapper valve. Then the fuel flows through the various layers until it gets upstairs, past the needle valve, and into the main cavity. I know this explanation still doesn't make any sense.



Ignition

Things to be discussed in this section are:

- The spark, and several kinds of ignition systems.
- Ignition timing, and the engine conditions which determine best timing.
- The methods by which timing is adjusted.
- Related factors, including engine heating, pre-ignition, and detonation.

The fundamental fact is that the fuel-air charge does not explode all at once. If any part of it explodes, that is bad and harmful to the engine.

To get maximum torque, we want to use the combustion pressure as efficiently as possible. It would seem to be ideal if we would cause this pressure not to start increasing at all until the piston reached TDC, and then to expend all of its energy in forcing the piston downward.

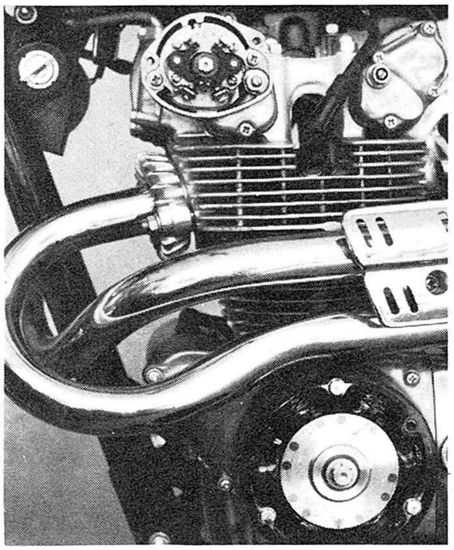
Since instantaneous combustion is neither desirable nor normal, ignition timing must take into account the interval of time which is required for the mixture to burn.

The spark occurs before TDC, as the piston is still rising. This means that the pressure increase due to heat of combustion starts to build up before TDC and is trying to push the piston back down. In effect, trying to make the engine run backwards.

You can feel this happening, sometimes, when using a kick starter. The engine will fire once. If there is not enough rotational energy in the crankshaft to push the piston past TDC in the face of increasing pressure, the piston will go down instead of up. The kick-start lever may hurt the bottom of your foot.

We use some of the energy in the mixture by starting it to burn early, in order to have some useful pressure built up when the piston passes TDC and starts downward on the power stroke. The rest of the energy is then available to push the piston down, to heat up the metal parts of the engine, and to heat up the exhaust gases.

Maximum thermal efficiency will occur when half of the burning time is before TDC and half after TDC. Thermal efficiency means how much of the heat energy is converted into mechanical



energy.

It is helpful to have a mental picture of the pressure and volume relationships in the combustion space above the piston.

Before TDC, the mixture is mechanically compressed by the upward movement of the piston, assuming both inlet and exhaust are closed.

When the spark occurs, cylinder pressure is increased additionally, due to heat of combustion. At TDC, the increase in pressure due to mechanical compression by the piston is at maximum. However, the pressure increase due to combustion is still on the rise. Total pressure above the piston should occur a few degrees after TDC.

As the piston moves downward from TDC, on the power stroke, the volume above the piston increases, which automatically starts reducing pressure, because the gases expand to fill up the larger volume.

The work extracted from the pressure-energy is, of course, the product of the average force times the distance traveled by the piston.

Since the distance is fixed by the design of the engine, the problem reduces to an apparently simple one—we want the highest possible force exerted on the piston during the time it is moving downward.

Maximum average pressure occurs when most of the burning occurs while the piston is near TDC, and this is accomplished by timing the start of burning to be ahead of TDC. Ignition normally commences somewhere between 10 and 50 degrees before TDC (BTDC).

TIMING SPECIFICATIONS

Manufacturers specify normal ignition timing for motorcycle engines using one or more of three methods:

1. A common way is to specify how far, in distance, the piston should be from TDC when the spark happens. To use this information, the tuner must use some reasonably accurate measuring instrument to read piston position. First, TDC is located, and then the engine is rotated *backwards* to locate the piston the correct distance BTDC. Then, the ignition mechanism is adjusted so it makes the spark at that point.
2. Another way is to state ignition timing rotationally, in degrees of crankshaft rotation.
3. The third method is to state ignition timing in terms of some distance to be measured around the perimeter of a flywheel.

The latter two methods are essentially the same, since degrees around a flywheel and distance around a flywheel are related simply by the diameter of the flywheel.

All three of the methods are basically the same information since every position of the crankshaft denotes some particular position of the piston.

When the flywheel is used as the timing indicator, there will be a mark on the flywheel which registers with a reference mark on the engine case to indicate the position where the spark should occur.

On four-stroke engines, the ignition system is often associated with the valve gear. Because both valving and ignition should occur once every second revolution of the crankshaft, the valve-train is operated at one-half engine speed by gear reduction. It is convenient to operate the ignition system at the same RPM as the valve system. In this case, the timing marks may be on the ignition rotor or some other location which is driven at half engine speed.

If you imagine that the crankshaft has turned through 20 degrees, then a half-speed camshaft will have turned through only ten degrees. For four-stroke engines, it is customary to state the timing for the ignition in degrees BTDC, and then state where this measurement is to be taken. As an example: 42 degrees on the crankshaft, or 21 degrees at the ignition rotor.

Shop manuals may use one or more ways to specify ignition timing. It is important to recognize that they all mean the same thing. It is pointless to set timing by piston position, then try to set it again by flywheel angle, and then try to polish it up by setting for flywheel distance.

If any one of those settings is different than the others, something is buggered up. Likely, the tuner.

EFFECT OF RPM

So far, it all sounds pretty simple. There is some amount of time required for combustion, we want about half of that time interval to be BTDC, and we do that by timing the spark at some point BTDC.

If the spark is set to occur at, say, 30 degrees BTDC and the engine is running at 1,000 RPM, then there is some measurable (or figurable) time interval between the ignition point and TDC.

If the engine runs twice as fast, 2,000 RPM, that amount of time is cut in half. If the engine runs at 4,000 and then 8,000 RPM, the time available is halved again at each step. At 8,000 RPM, the amount of time BTDC allowed by a fixed ignition setting is only 1/8 as much as at 1,000 RPM.

This suggests that the ignition point should be advanced as RPM increases, in order to allow the same amount of time for burning at high RPM as at lower RPM. Advance means to happen earlier, or more degrees ahead of TDC. Retard means the opposite.

COMBUSTION FACTORS

Proper ignition timing relates to two fundamental things. One is the RPM of the engine. The other is the actual time required to burn a charge of fuel-air. Burning time gets pretty complicated. Here are some rules:

Burning time is shortened by:
- **Higher pressure**
- **Higher temperature**
- **Higher air density**
- **Richer mixture**
- **More turbulence**

Burning time is lengthened by:
- **Lower pressure**
- **Lower temperature**
- **Lower air density**
- **Leaner mixture**
- **Less turbulence**
- **Residual burned gases**

When the mixture is compacted more, due to pressure, the flame can travel from one burning set of molecules to the next unburned set more quickly, and combustion is faster.

The density of air drawn into the engine affects pressure directly. Also, because there is more to burn, combustion pressure is higher. Higher densities cause shorter burning times. At higher altitudes, where density is lower, burning should take longer and additional spark advance is indicated.

Rich or lean mixtures affect burning time in a way analagous to the maximum-power and maximum-economy ideas. Rich mixtures encourage both complete and prompt burning of the oxygen.

Burned gases which do not go out the exhaust are no longer burnable. They absorb heat, infiltrate and separate the molecules of fresh charge. The result is slower burning. This "pollution" of fresh charge is greatest at part throttle and idling speed.

Among all of the factors influencing speed of burning, turbulence is the most important. If a mixture is quiet, burning occurs by a traveling flame front and the time of burning is that required for the flame front to travel to the most distant part of the combustion space.

If the mixture is turbulent, then portions of mixture are being swirled into the flame front and do not have to wait for its arrival. Burning time in a turbulent mixture can be ten times shorter than in a non-turbulent mixture. Engines with good turbulence run more economically!

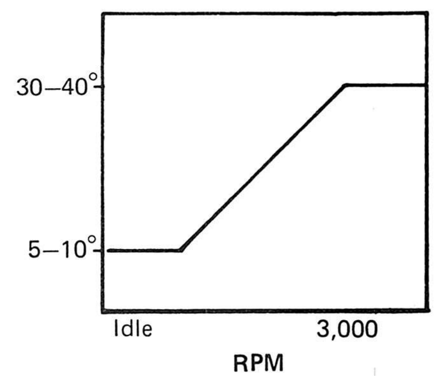
TYPICAL TIMING

It is customary to make a graph showing ignition advance against engine speed for a particular engine. The advance starts at some small amount, such as 10 degrees, and then increases with engine speed, in order to allow some nearly constant time for burning.

As RPM increases, turbulence begins to affect burning time due to the increased kinetic energy of the gases and due to the faster motion of the piston. Also, the combustion chamber may be shaped so that the piston, as it rises, makes the mixture swirl or squishes it from the periphery of the combustion chamber, toward the center. In a two-stroke, the direction of the ports (transfer and boost) *strongly* affects turbulence.

At some speed, around 3,000 RPM in some engines, the increased turbulence due to higher RPM offsets the reduced time available for burning. At that point, the spark advance required becomes nearly constant up to the highest speed of the engine.

It is important to recognize that ignition timing curves display only the effect of RPM and turbulence in combination, and do not show timing changes required by any of the other factors listed above.



A spark advance curve for no particular engine. All engines use less advance at low RPM and some fixed amount of advance above mid-range RPM, for reasons described in the text. The basic idea of spark advance is not clear to some people and they will argue with you about it. The spark occurs at some point in time before the piston reaches TDC on the upstroke. The interval between ignition and TDC is usually expressed in degrees of rotation and that interval represents the amount that the spark is *advanced* in respect to the piston arriving at TDC. If the spark happens sooner, that is more degrees ahead of TDC, it is *more* advanced. Twenty degrees BTDC is more advanced than ten degrees BTDC.

CONTROL OF TIMING

Spark advance is controlled, in various engines, in three ways:
1. Fixed ignition. Timing is set and does not vary with RPM.
2. Centrifugal advance. Timing is advanced by a centrifugal mechanism (rotating weights) up to a certain RPM and remains fixed above that RPM.
3. Vacuum advance. Timing is advanced or

retarded by a diaphragm which senses vacuum in an intake manifold, without regard to RPM. but in relation to engine load.

Fixed ignition and centrifugal advance are both commonly used on motorcycles. Automobiles use centrifugal, vacuum, and sometimes both in combination.

With the advent of emission controls on internal combustion engines, motorcycle ignitions of the future are likely to resemble automotive ignition systems more than they do today.

Fixed ignition timing, on a motorcycle, obviously cannot cater to the ignition advance requirements of the engine. It is either a compromise setting, or one which tends to favor operation at one end of the speed range.

No ignition system can automatically do the tuner's job. That is, set the timing properly with the correct static advance (or low RPM setting), the correct amount of centrifugal advance if the mechanism is there, and corrections for different operating conditions due to mixture, quality of fuel, air density, and compression changes due either to engine wear or modification.

Most hop-up procedures improve engine breathing, compression, or both. Either results in higher compression pressure. The hop-up instructions will usually say, "After this is done, retard the spark." This is because increased compression typically shortens the burning time requirement, hence less advance is required.

When a manufacturer makes two versions of the same engine, enduro and MX for example, the higher power engine will require less advance.

TUNING PAYOFF

Because stock ignition settings are determined at the factory, under some standard conditions, the careful tuner can find a small percentage increase in performance if he is not operating under those standard conditions. If the stock timing is a compromise between low and high RPM requirements, the tuner can choose to favor either by changing the timing. If the bike is operated at a higher altitude, with a different mixture, or with modifications to inlet, exhaust, or the engine itself, the stock timing will not be exactly right.

HEATING

Heating is the enemy, particularly with air-cooled engines. Improper timing can drastically increase heating and can destroy an engine. The tuner has to be very alert to heating, using methods to be described later.

Since the working process of an engine converts heat to mechanical energy, the tuner is presented with an attractive proposition. Tune it for maximum power and it will have minimum heat left over to melt pistons.

This proposition leads to a fork in the road. If the engine is exactly stock, you can reasonably expect that it can stand the development of maximum power without destroying itself. With a stock engine, maximum power may be limited by detonation, as discussed below.

If the engine has been modified, you are on your own. If it takes in more mixture, there is more total heat-energy present. Even if the engine is tuned for best thermal efficiency, the residual heat that is not transformed into mechanical work will be higher than when less mixture is burned. The result can be engine damage to a properly adjusted—but modified—engine.

DETONATION

At some elevated temperature and pressure, a pocket of unburned mixture will explode violently, without regard to normal ignition and without waiting for the flame front to ignite it.

The resulting pressure-wave is sudden and violent. It can break pistons, destroy con-rod bearings, and fracture the insulator of the spark plug. If it breaks the plug and the engine quits, that's good. Every second that an engine runs while detonating brings it closer to damage.

The sharp hammer-blows of detonation cause a characteristic sound, usually described as knocking or pinging. Most of the time, hearing detonation is the only way to know that it is happening, until it is too late. A loud exhaust can prevent you from hearing it.

Fuel additives, such as tetra-ethyl lead, cause gasoline to resist detonation, or detonate at higher temperatures and pressures.

Since thermal efficiency is aided by high combustion pressures, we have seen a hand-in-hand increase in engine compression ratios and improved fuels. The ability of a fuel to resist detonation is expressed by the octane rating, higher numbers meaning greater resistance to detonation.

Current emission controls have reversed the trend. Engine compression ratios are going down and fuels are being produced with lower octane ratings due to the reduction of lead content. It is getting harder and harder to buy good gasoline from the usual corner filling stations.

With any engine, and any fuel, detonation must be prevented. The simplest way is to use a better fuel, but if this is not possible, then some way must be found to reduce cylinder pressure, or temperature, or both.

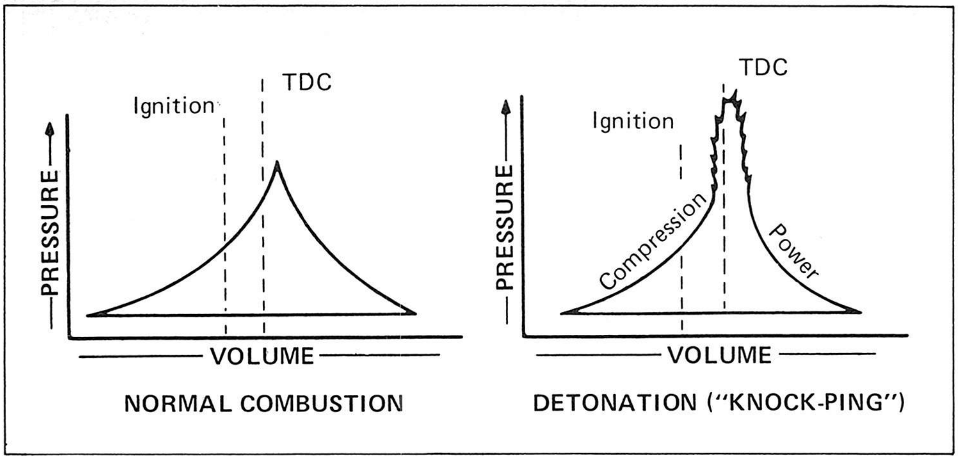
The standard cure for detonation is to retard the spark. This burns less mixture before TDC and more of it after, when combustion volume is increasing. The result is that the peak cylinder pressure is reduced and there is less tendency for detonation to occur.

The by-products of this "cure" are less engine power and more heat. A secondary "cure" is to run more rich, hoping that the cooling effect of excess fuel will hold down the engine temperature enough to avoid detonation.

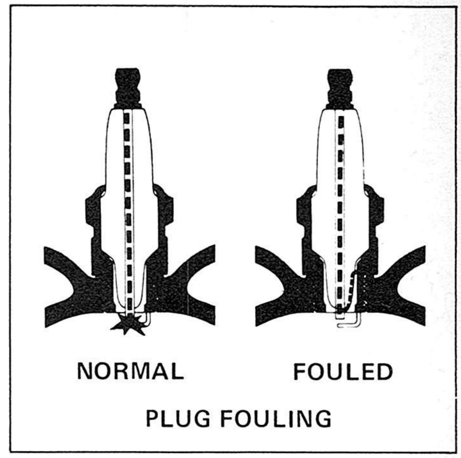
Some high-performance engines come right out of the factory with the potential of detonating even with the best available gasoline. These engines are comparable to an owner-modified engine with good breathing and high compression. The rule, for an engine of this sort, is to advance the timing to the point where detonation just begins, and then retard the spark a few degrees, possibly two. The idea is that this gets the engine as high up on the power curve as can be tolerated.

On an owner-modified engine, there is the possibility that you can advance spark to the point of best torque or power and then continue advancing (with power decreasing) until you find detonation. In this case, more of the mixture is burning before TDC, when combustion volume is getting smaller, so peak cylinder pressure is occurring before TDC, causing detonation. If the tuner retards a couple of degrees from that timing, the engine may still be operating below its power peak, on the "advanced" side.

The point is, it's better to measure power than to assume it is always best at some specified timing, or when timing is just short of detonation.



With normal combustion, cylinder-head pressure rises to a peak value just after TDC, then pressure decreases because the piston is moving down and volume is increasing. When detonation is provoked by high pressure and temperature the normal burning gives way to an explosion of the mixture above the piston. This would be OK if the mechanical parts could withstand the hammer-blow impacts of detonation. They can't in a normal internal-combustion engine and damage will result. When you hear the rattling, pinging sound of detonation, stop using the engine so it does that. Fix the problem before you have to fix the engine.



This drawing, courtesy of Champion Spark Plug Company, shows normal ignition with the electrical current behaving itself, jumping the gap at the end of the spark plug and making the spark. It also shows what happens when the spark plug gets fouled. The fouling on the insulator provides an easy path for current from the center electrode over to the metal shell of the plug. The current takes this detour, does not jump across the gap, does not make a spark.

The second point is that maximum power may not be obtainable, due to the onset of detonation.

PRE-IGNITION

A close cousin to detonation is pre-ignition, and one may cause the other.

If an engine is generating more heat than it is getting rid of, the temperature will gradually increase.

At some elevated temperature, the fresh charge will ignite soon after it enters the combustion space, without waiting for the spark. Sometimes this form of ignition will occur at about the right time anyway and the engine will run just fine even though it is pre-igniting. Some model-airplane engines run that way, using a "glow plug" which retains enough heat from the previous combustion cycles to ignite each fresh charge.

On most engines, not designed to run while pre-igniting, the timing due to pre-ignition will be early as the name implies. This causes less power, more heat which leads to still earlier pre-ignition, and leads to a runaway condition in which the engine will melt a piston or seize. Also, the early ignition and increased heat can lead the engine into detonation.

The tendency to pre-ignite is made worse by anything in the combustion chamber which holds heat and can become glowing hot. This can be a sharp corner of the spark-plug opening, the glowing end of the spark plug itself, or glowing bits of combustion deposits on the head or top of the piston.

Spark plugs are discussed in more detail elsewhere, however now is a good time to mention that pre-ignition is the reason plugs are made in different heat ranges. A cold plug tends to run at a lower temperature in an engine. If there is evidence that a plug has been running too hot, one of the things that can be considered is changing to a colder spark plug.

The early evidence of pre-ignition is shown by the spark plug. If it is the correct heat-rating for the engine, and it is getting too hot, there is excessive heat and the possibility of pre-ignition.

The cure is to clean up the combustion chamber and tune the engine properly. And make sure there are no exposed plug threads.

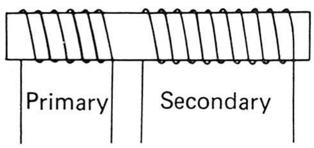
HOW SPARKS ARE MADE

The spark is a pulse of electric current which jumps across the gap between the center electrode (wire) and the side electrode of the spark plug. In the process, it heats the small volume of mixture along the path of the spark. If this raises the temperature of the mixture to the combustion point, then combustion will begin and should continue, generating its own heat as it progresses.

The spark gap, at the plug, is usually 0.015 inch to 0.025 inch, or in that neighborhood. The voltage required to cause the spark is around 15,000 to 20,000 volts.

Higher compression requires a higher voltage to jump the gap. A plug that fires outside of the engine may not necessarily fire when exposed to the higher pressure in the engine. However, increased temperature of the plug and mixture tend to reduce the voltage required, so these two effects offset each other to some degree.

If the plug is fouled by combustion deposits on the insulator, or by unburned fuel or oil, the deposits will usually be electrically conductive. Then,



SPARK COIL

A spark coil multiplies a low voltage across the primary winding to become a high voltage across the secondary winding. The trick is many more turns of wire on the secondary coil. In the real world, the two wires in the middle—one end of the primary and one end of the secondary are often connected together and connected internally to the metal parts of the spark coil. When the spark coil is bolted to the frame of the motorcycle both primary and secondary coils are grounded electrically. This is why real-world coils usually have only two external wires—a small one to the ignition and a heavily-insulated high-voltage lead to the spark plug.

the electric current can flow along the conductive path and reach the side electrode without having to jump the gap at all. There will be no spark.

Or, some of the current can take the alternate path and some can jump the gap, resulting in a weak spark which may not heat up the mixture enough to start combustion.

All conventional ignition systems generate a pulse of electricity at a relatively low voltage and then rely on an electrical transformer to increase the voltage to the needed high value.

This transformer, on a motorcycle, usually hangs on the frame underneath the gas tank. You can always find it by following the large insulated wire from the top of the spark plug.

It is usually called a coil, sometimes a spark coil, because inside it is a lot of wire, all coiled up. There are two coils, in effect, the primary winding and the secondary. The trick lies in the fact that the secondary has many more turns of wire than the primary.

A current, changing in value as it flows through a wire, creates a changing magnetic field around the wire. The process is reversible. If a magnetic field is caused to change around a wire, it will cause a voltage and if there is a path, electric current will flow as a result of the changing magnetic field. This is called induction.

The basic idea is that we wind the two coils on a common iron core so that the magnetic field is also common to the two coils. The primary winding receives the low-voltage ignition pulse and creates a magnetic field. The magnetic field then induces a much higher voltage in the secondary winding, and the higher voltage causes the spark at the spark plug.

The next trick results from the fact that the rate of change of the magnetic field influences the value of induced voltage. If the magnetic field changes very rapidly, that will generate a higher voltage in the coil.

The abrupt change in the magnetic field is caused by an abrupt change in current flow in the primary winding of the spark coil which, in turn, is caused by the sudden action of a switch.

In a conventional ignition, this switch is two electrical contacts which are opened and closed by a cam. They are called ignition points, or contact points, or something like that.

Most standard descriptions of how ignitions work are based on use of a battery to supply a flow of current into the spark coil. When a spark is desired, the ignition points are caused to open, which interrupts the flow of current suddenly. In this case, the spark is caused by the cessation of current flow in the coil. Some writers overwork the point and seem to leave the impression that only an interruption of current flow will do the job.

This is not correct. As we will see, many motorcycle ignitions cause the spark to occur when current begins to flow in the spark coil, rather than when it ends.

If you want to consider the current into the primary of the coil as a pulse, then the spark can be generated by the leading edge or the trailing edge of the pulse. The coil operates on the change of current value, and doesn't care much in which direction.

A simple ignition coil will have two wires. The large-diameter wire has more insulation and carries the high-voltage spark pulse down to the spark plug. The smaller wire brings the low-voltage current pulse into the primary of the coil.

At the opposite end of the small wire is the rest of the ignition system.

TYPES OF IGNITIONS

There are several kinds of ignition systems:

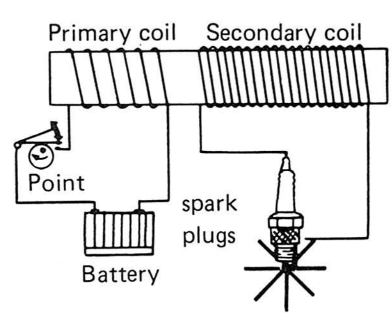
- Battery-coil
- Magneto
- Battery-electronic
- Magneto-electronic

The battery types draw current from the vehicle battery and the only thing they have to do is make a pulse from this current and time it so it happens when needed.

The magneto types have a somewhat more complicated job. They must first generate the current that they will use, then shape and time the pulse. The word "magneto" means generator. It acts as a generator by whirling some magnets past a stationary coil and inducing a voltage in the coil which will cause electric current flow if there is a path.

Since motorcycle magnetos rotate the magnets by putting them in a flywheel on the end of the crankshaft, this is sometimes called a *flywheel-magneto ignition.*

Battery-coil ignition works like this: Current from vehicle battery flows through primary coil until rotating cam opens points. Sudden change in primary current induces big voltage in secondary coil which causes current to leap across plug gap and make hot spark. Spark is timed by cam opening points.



BATTERY-COIL IGNITION

It is also called an *energy transfer* system, and the idea is that electrical energy from the magneto is transferred up to the spark coil where the rest of the job gets done.

BATTERY-COIL IGNITION

Let's start with a typical battery ignition and chase the electrons. Current comes out of the "hot" side of the battery, and the other side of the battery is grounded to the frame of the bike.

Current flows through the key-switch if there and then through the primary winding of the spark coil. There is normally a fuse between battery and switch, however it is left out of the accompanying diagram. For simplicity only ignition-related parts are shown.

Leaving the other end of the primary, the current flows past the condenser, through a flat spring on the contact point set, and to the movable point. If the points are closed, current flows from the movable point to the non-movable point. The stationary point is grounded and the circuit is completed back to the battery through the frame of the motorcycle.

If the ignition points are open, no current will flow anywhere in the circuit just described.

The points are opened and closed by a cam which is driven by the engine. If you assume current is flowing, and the points are then suddenly opened by the cam, current will stop. A high voltage will occur in the secondary of the spark coil. This delivers a mighty zap to the plug and it makes a spark.

It is evident that ignition timing is determined by the cam opening the points. Later we will discuss how timing is adjusted.

If the cam is on the end of the crankshaft, it will make one spark per crank revolution, which is just right for two-strokes.

If the bike is a four-stroke, this arrangement will produce one spark near the end of the compression stroke, as it should. It will also make another spark when the piston is near the end of the exhaust stroke which is not useful but doesn't hurt anything unless the exhaust is combustible.

Other four-strokes drive the ignition at half-speed and don't waste any sparks.

THE CONDENSER

There has been more drivel written to explain the action of the condenser in ordinary words than either you or I care to read.

It is not possible to explain what it does, in ordinary words.

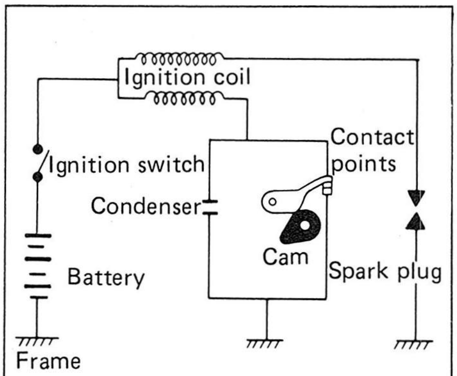
The result of what it does is that the points do not burn or pit as much as they would without a condenser across the circuit. When it works, it does its thing quietly and with no bother.

When it fails, the condenser will usually develop a short circuit, or low resistance, which diverts the ignition current to ground and causes a weak spark or none at all. Cure is to replace it.

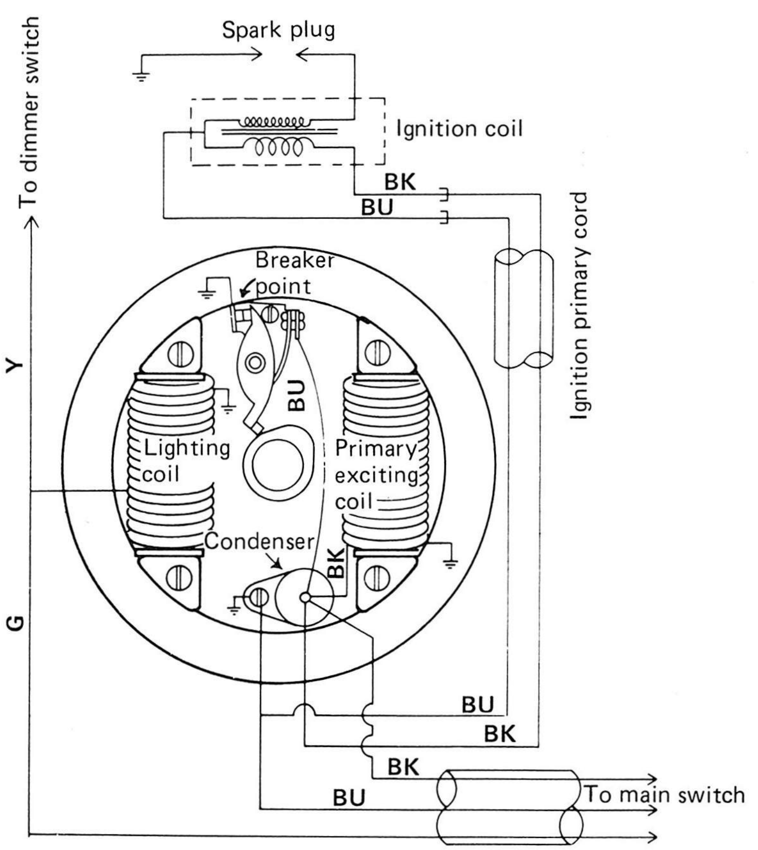
FLYWHEEL MAGNETO

As shown in the diagram, one end of the ignition source coil (Primary Exciting Coil) is connected to the electrical ground of the motorcycle. The wire from the other end (marked BK for black color) is connected to the condenser, and at that connection point branches out three ways.

One wire goes to a terminal on the breaker point set and connects to the spring, which is electrically connected to the movable breaker point. The stationary point is electrically grounded.



BATTERY-COIL IGNITION



MAGNETO/ALTERNATOR WIRING DIAGRAM

If the points are closed, that's where the current from the source coil goes—through the points and to ground.

When a spark is desired, the points are opened by the cam. Current can no longer be short-circuited to ground by the closed points, so it flows along the black wire up to the spark coil under the fuel tank, and through the primary. This sudden burst of current causes the spark.

The other end of the spark-coil primary winding is grounded by the blue (BU) wire which returns from the coil. This is a more reliable ground than simply attaching the coil to the frame for an electrical ground.

Anyone familiar with Hodaka will recognize these color-coded wires. That's where this diagram came from.

The black wire from the terminal on the condenser which goes to the main switch is the ignition on-off function. When the main key-switch is off, this wire is grounded, so no current can flow to the spark coil. If a kill-button is installed, it will connect to the black wire leading to the spark coil. When the kill-button is depressed, it grounds this circuit, killing the spark.

The magnets in the flywheel, as they rotate, induce voltage in more than one coil. The lighting coil keeps the battery charged and supplies current for the other chassis electrical items.

As a magnet passes by the ignition source coil, the voltage in the coil rises to a peak and then diminishes as the magnet goes away. This is both handy and unhandy.

The handy part is that the ignition voltage falls off gradually after making each spark. When the cam allows the points to close this abruptly cuts off current flow in the spark coil, but this does not cause a second spark because the current has already fallen to some low value.

The unhandy part is that the flywheel magneto ignition must be adjusted so that the spark is made with the strongest part of the electrical output of the exciting coil. This is part of ignition timing, as we will see.

ELECTRONIC IGNITIONS

Electronic ignitions have several advantages. They usually do not use mechanical points to time the spark and therefore avoid problems due to mechanical and electrical wear of the points.

They usually generate a higher-voltage spark than a conventional ignition.

They sometimes make a spark with a faster rise-time than a conventional ignition. The faster rise time gives them the ability to fire a plug which is fouled.

Rise time is important because it determines how long it takes for the voltage pulse at the spark plug to rise to the value necessary to make the spark jump across the gap. If there is an alternate path for current flow, due to fouling or combustion deposits on the insulator of the plug, then two things are happening at the same time.

The spark pulse is climbing, at some rate, toward the value which will cause the spark. The leakage current through the alternate path created by fouling is reducing the voltage of the spark pulse.

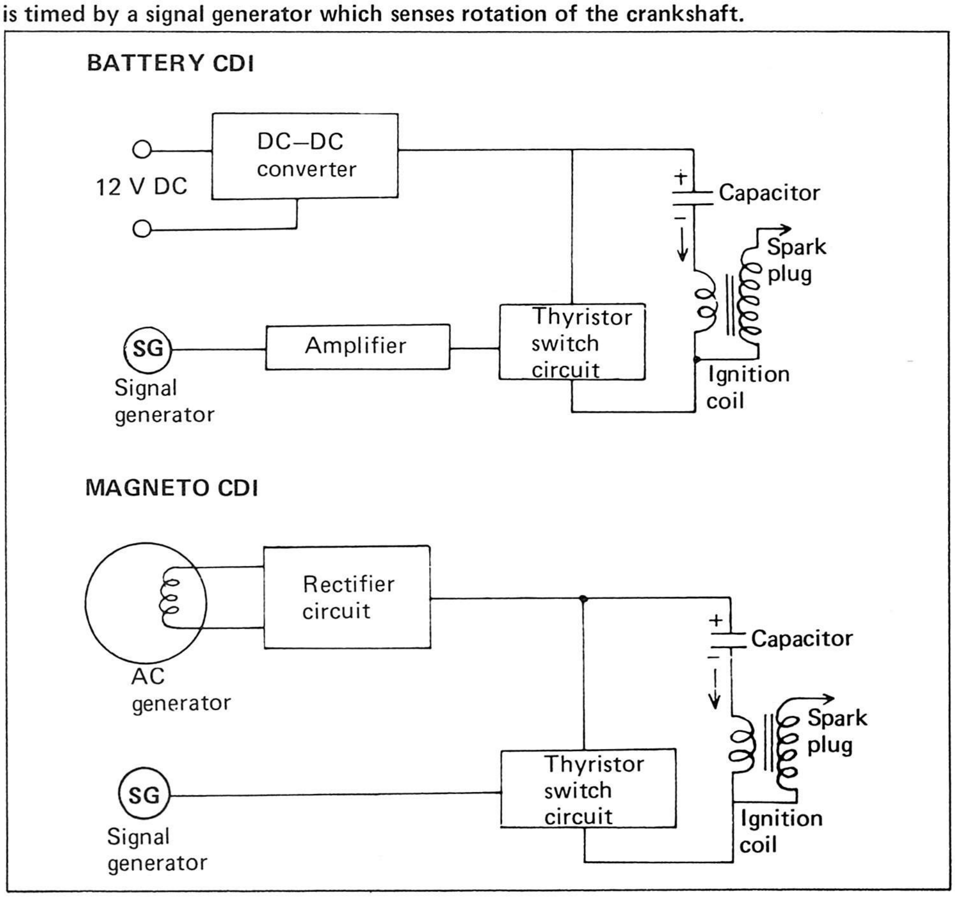
The contest is determined by the time-rates. If the spark pulse can get up to firing voltage before the leakage current bleeds away its energy, then it will make a spark. If the spark pulse rises slowly, then the leakage current may draw away its energy before it can reach the high voltage necessary to create a spark.

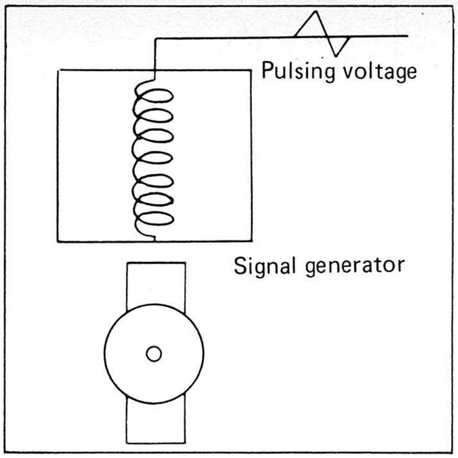
Electronic ignitions, typical of present types, generally have such fast rise times that they literally make the spark before the leakage current can have any effect.

Advertising of electronic ignitions often says that because they don't have mechanical point wear, the timing never changes. This is true, however that does not mean that the timing is right.

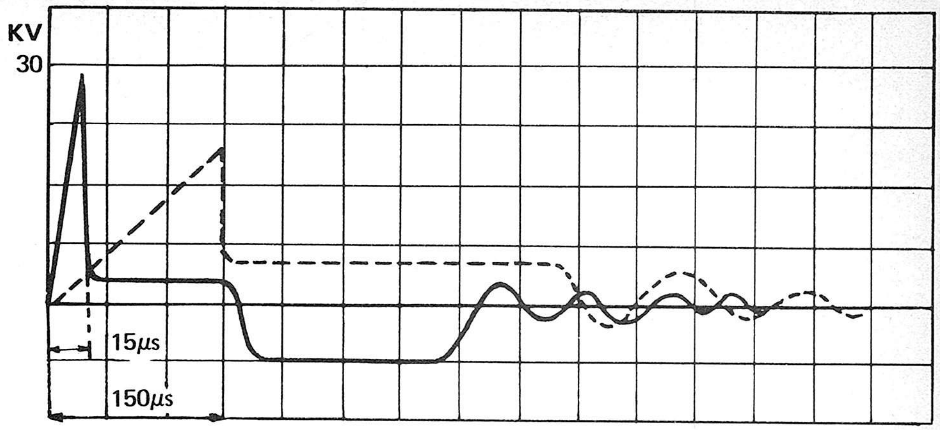
These ignitions have timing adjustments, same as others, and are adjusted the same way and for the same reasons. The big advantage is that after you get it set for a particular condition, it will not change due to wear. If

Capacitor-discharge ignition, when fed by a battery, only has to make the spark. When fed by a magneto it has to generate its own voltage, then make the spark. Either system is timed by a signal generator which senses rotation of the crankshaft.





The signal generator which times a CDI ignition is a small pickup coil mounted close to a rotating magnet. When the engine rotates, the magnet sweeps past the pickup coil generating a small pulse of voltage which is used to trigger the spark.



One advantage of CDI is the spark gets there in a hurry and rises to a higher value. Solid curve shows quick rise-time of CDI spark, dotted curve shows slower rise-time of conventional ignition.

the operating conditions change, perhaps air density, then the timing may need changing also.

The source voltage for an electronic ignition may be either the vehicle battery or a source coil in a flywheel magneto.

The major disadvantage of this type of ignition is that failure is usually catastrophic. When it quits, it does so suddenly and completely. You can't fiddle with it and get it working well enough to ride home.

In general, though, they are reliable and have distinct advantages over other types. At this time, the majority of ignitions on bikes use mechanical points and this type is referred to as "conventional."

The drawings in this section, furnished by Kawasaki, help to explain the two types of electronic ignitions.

CDI means *capacitor discharge ignition.* "Capacitor" is another name for an electrical condenser.

You don't have to be an electronic whiz to understand the basics of these ignitions, and it's worth doing because, if you don't have one on your present bike, you probably will on the next.

In both diagrams, notice the capacitor, near the ignition coil. A property of the capacitor, which is used in these ignitions, is its ability to charge up exactly like a battery, and discharge in the same way.

Imagine that the capacitor has received a charge and is holding it until needed.

The *thyristor switch circuit* is exactly that—a switch which works electronically, rather than mechanically. Its function is identical to the function of mechanical points, except that it does not suffer mechanical wear.

Assume, now, that the switch closes. The current stored in the capacitor will flow through the primary of the ignition coil, through the switch, and back to the other side of the capacitor.

That makes the spark.

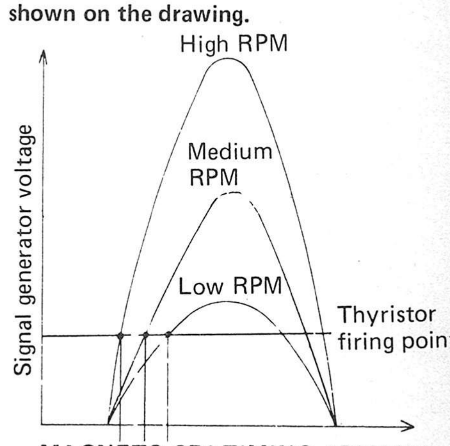
In order to store enough energy in the capacitor to ignite the mixture in the cylinder, and keep the capacitor to a reasonable size, it must be charged up to a higher voltage than the vehicle battery can supply.

In the case of Battery CDI, this calls for a DC-DC converter, which is an electronic circuit. The converter takes 12 volts from the battery and multiplies it up to about 400 volts. This 400 volts is then fed over to the capacitor, to charge it up again between sparks.

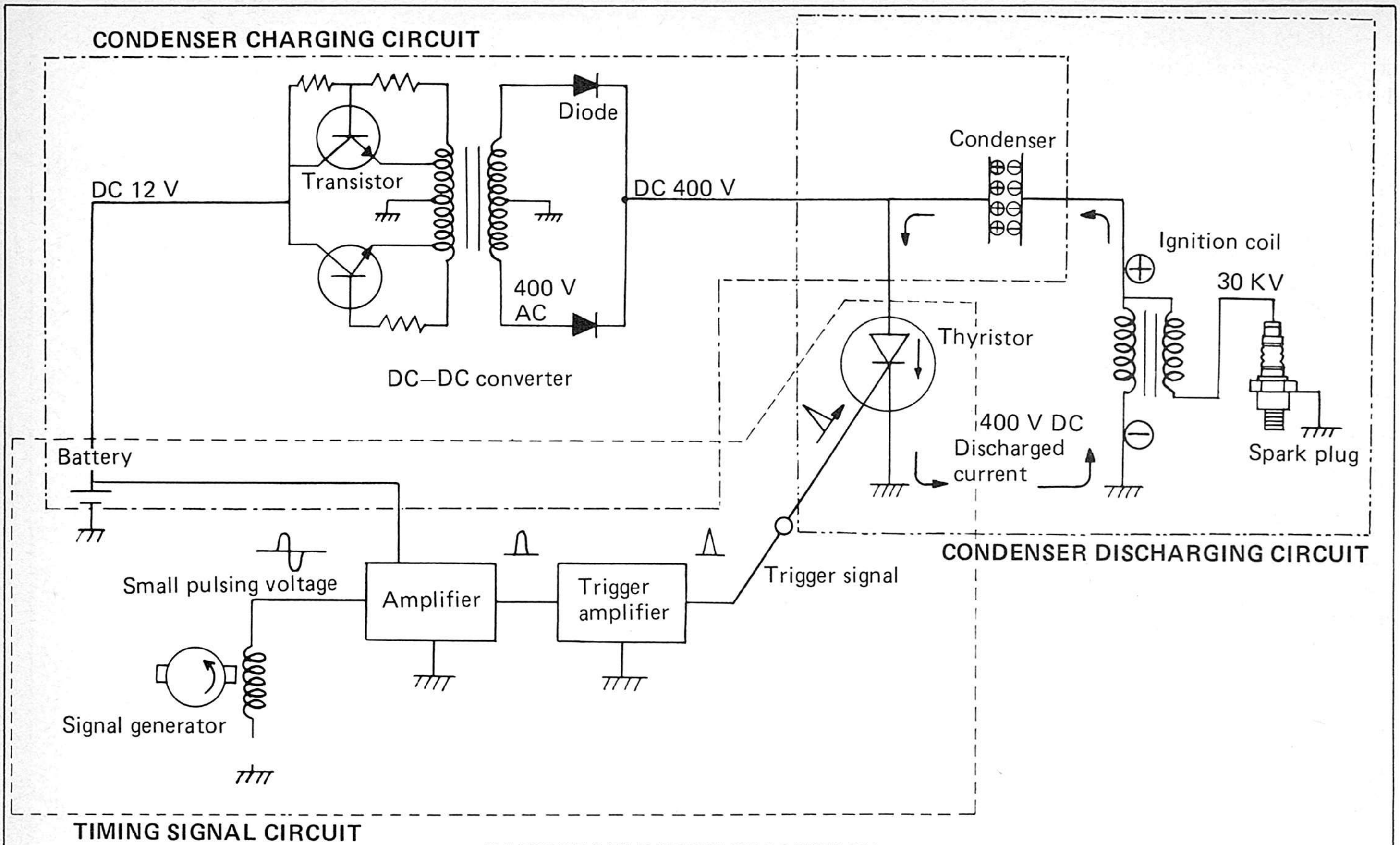
The remaining problem is to operate the thyristor switch. This is done by a pulse of voltage which happens at the proper time in relation to crankshaft rotation.

The trigger pulse is generated by a rotating magnet which may be on the end of the crankshaft. As the magnet

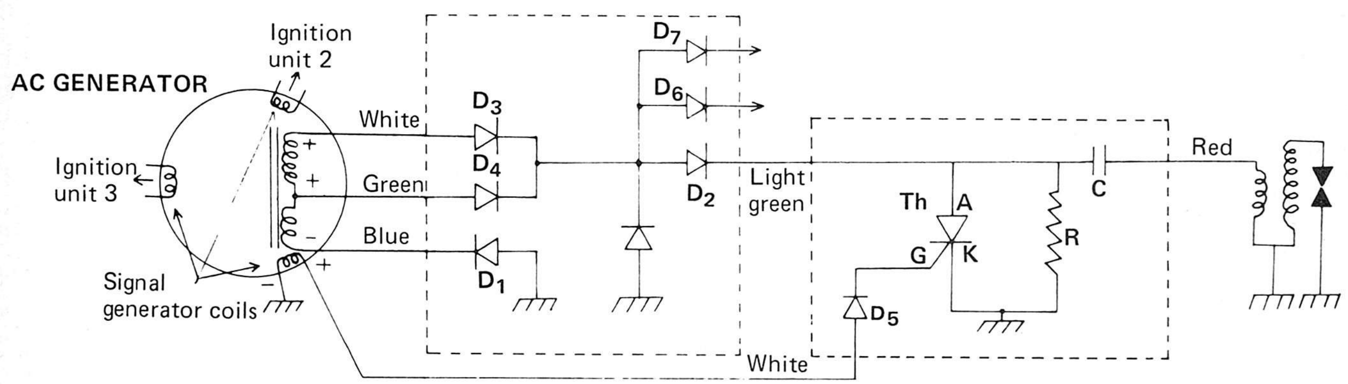
A significant advantage of CDI is that it can provide some spark advance automatically. The trigger pulse which fires the thyristor switch is generated by a rotating magnet. The generated voltage will be higher as the magnet rotates faster. Not only is it higher, but also it rises faster. Since the thyristor switch triggers at some fixed voltage, as the drawing shows, a faster rise time will switch it earlier. This provides an automatic spark advance with increasing RPM. Three firing points are shown on the drawing.



MAGNETO CDI TIMING ADVANCE



BATTERY-ELECTRONIC IGNITION



MAGNETO-ELECTRONIC IGNITION

For those who want more information, here are two circuit diagrams of CDI ignitions: battery—above, magneto—below. In some applications of the battery type, the electronic "boxes" are not duplicated for multiple-cylinder engines. Spark is directed to the proper cylinder at the proper time by a rotating distributor similar to automobile practice.

The magneto CDI is shown for a three-cylinder application. The source coil serves all three cylinders. There are three pickup coils at 120 degrees around the stator. Each drives its own thyristor switch. The other two switches are fed high voltage by diodes D_6 and D_7.

Diodes D_3 and D_4 select the higher voltage from the source coil. The segment blue-green has more turns to generate adequate voltage at low RPM. As speed increases, the IR drop in this segment becomes excessive. The green-white segment has fewer turns of larger wire, generating an equivalent voltage at high RPM, but with smaller IR drop under load.

passes by a small pickup coil (signal generator coil) it makes a pulse of electricity which feeds over to the electronic switch and causes it to close.

The rotating magnet, pickup coil, and thyristor switch, in an electronic ignition, serve exactly the same purpose as the cam and points on a conventional ignition.

In the battery CDI, an amplifier is interposed between the pickup coil and the switch, in order to make the pulse larger.

Magneto CDI systems have one big advantage over the battery CDI. By using the flywheel magneto and a source coil (not the pickup coil) the necessary higher voltage needed by the capacitor can be generated directly without resort to an electronic converter. This reduces the number of electronic parts and tends to make the system more reliable.

The voltage generated by the rotating magnets in the flywheel is AC (Alternating Current) however, and DC (Direct Current) is required for the capacitor. So the Magneto CDI uses a rectifier circuit which converts the AC to DC, but does not increase the voltage.

Typically, two-strokes run with fixed ignition timing because they tend to use flywheel magnetos, and building an advance mechanism into a flywheel magneto is complicated.

SETTING IGNITION TIMING

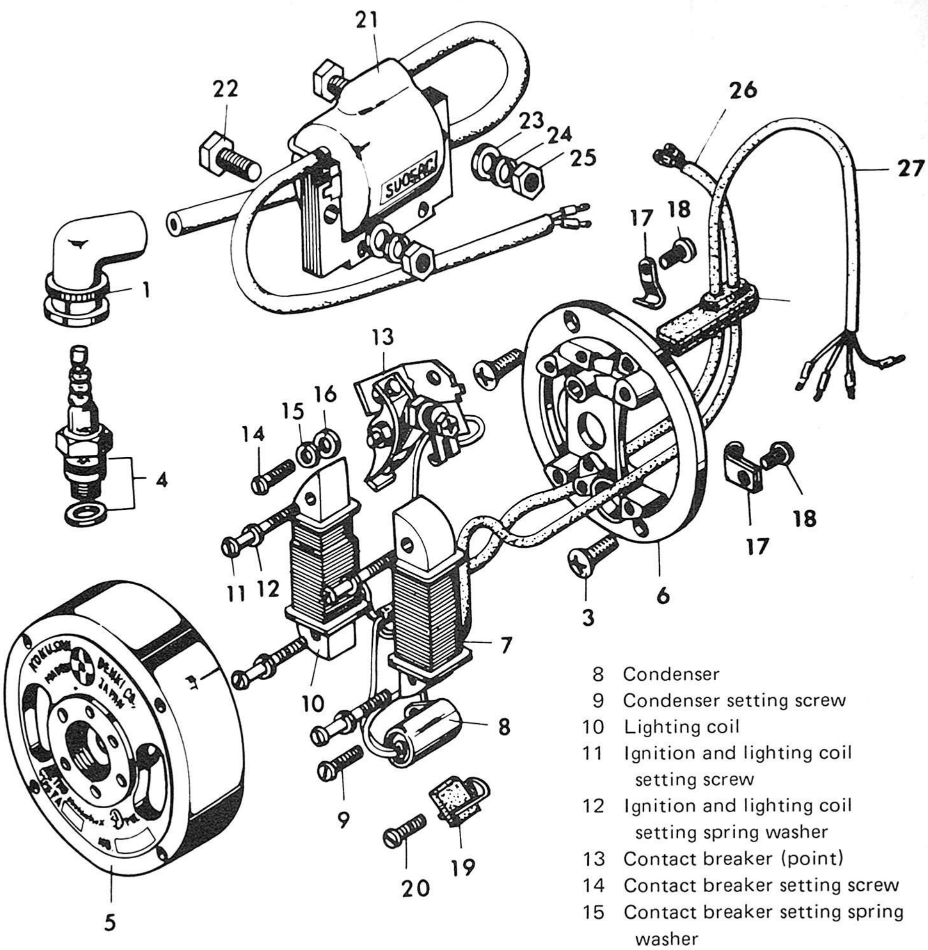
All ignition systems have parts in two categories: those that rotate and those that are stationary.

The spark occurs when some part of the rotating element comes into alignment with some part of the stationary element (stator).

Fundamentally, then, we time the spark by moving the stator, rotationally, and then locking it in place. This causes the spark-making alignment between rotor and stator to occur at some different angle, depending on which way the stator was moved.

This section will discuss the flywheel magneto since it is the most complicated. Other ignitions are similar as far as tuning adjustments are concerned.

The piston, crankshaft, and flywheel are all mechanically coupled together. The flywheel hub, on the inner side of the flywheel, is extended toward the engine and shaped as a cam, to operate the ignition points. Thus, the ignition cam is also part of the rotating component.



MAGNETO/ALTERNATOR COMPONENTS

Courtesy of PABATCO, importers of Hodaka.

1 Plug cap
2 Grommet
3 Frame setting screw
4 Spark plug B-8
5 Flywheel
6 Frame
7 Ignition primary coil
8 Condenser
9 Condenser setting screw
10 Lighting coil
11 Ignition and lighting coil setting screw
12 Ignition and lighting coil setting spring washer
13 Contact breaker (point)
14 Contact breaker setting screw
15 Contact breaker setting spring washer
16 Contact breaker setting washer
17 Wire cord stopper
18 Wire cord stopper setting screw
19 Felt lubrication pad
20 Felt lubrication pad setting screw
21 Ignition coil
22 Ignition coil setting bolt
23 Ignition coil setting washer
24 Ignition coil setting washer
25 Ignition coil setting nut
26 Ignition coil primary cord
27 Lighting coil cord

The rest of the parts do not rotate with the engine and are attached to the engine case. The source coil is mounted on a stator plate, and the ignition point set is also on the stator plate.

The stator is attached to the engine case, usually with three screws passing through elongated holes in the stator. By loosening the three screws, the stator can be rotated, and then fixed in the new position by tightening down the screws again.

The stator has a hole in its center and the end of the crankshaft passes through this hole on the way out to the flywheel. The flywheel is "hollow" on its inside face, and the parts on the stator fit into the cavity in the flywheel.

Magnets in the periphery of the flywheel pass by, very close to the ignition source coil, and any other coils that are mounted on the stator.

Imagine that a flywheel is rotating clockwise and

that, somewhere during each revolution the ignition cam on the flywheel is opening the ignition points, making the spark.

Now, imagine that the stator is moved a few degrees clockwise and locked in place again. The flywheel will have to travel farther in the clockwise direction before the cam can reach the place where it opens the points.

By rotating the stator in the direction of flywheel rotation, ignition timing was retarded. Moving the stator in the direction opposite to engine rotation makes everything happen earlier and advances the spark. It should be noted that movement of the stator plate not only rotates the point assembly, but also moves the source coil.

The point assembly mounts on the stator. Typically, a stud or extension on the back of the point set fits into a hole in the stator plate. A clamp screw holds the point set in place. When the clamp screw is loosened, the point set can be rotated on the stator. The pivot for rotation of the points is the stud on the back of the point assembly which, as noted, fits into a hole in the stator.

It is important to recognize that we have talked about two different adjustments. The stator can be rotated, and its center of rotation is the centerline of the crankshaft. On the stator plate, the points can be rotated and the center of rotation for the point set is a hole on the stator plate.

The effect of rotating the entire stator plate is to change the angular location where the cam on the flywheel opens the points.

The effect of rotating the point set itself is to move the fiber rubbing block, which engages the cam, closer to or farther away from the cam.

Imagine that the points are set so that the rubbing block is never touched by the cam—it passes by without making contact. Obviously, the points will never be opened. Now, bring the point set closer to the cam, so that the cam just barely opens them.

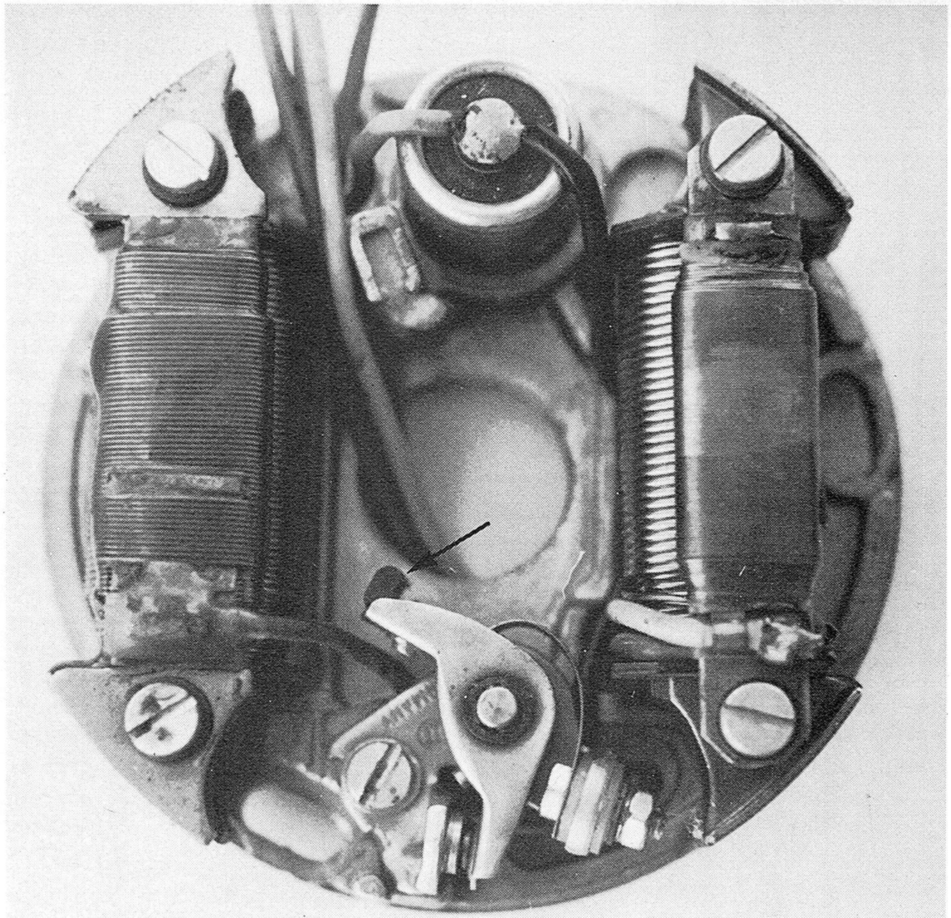
Engagement will be very near the tip of the cam lobe, and the points will open only a tiny amount.

Now, bring the point set still closer to the cam. The points will open more, and also open *earlier*, with respect to flywheel rotation. One of the specs on ignition timing with mechanical points is the gap between the points when they are held fully open by the cam. When this gap is made larger, the time of point opening is earlier, or more advanced BTDC.

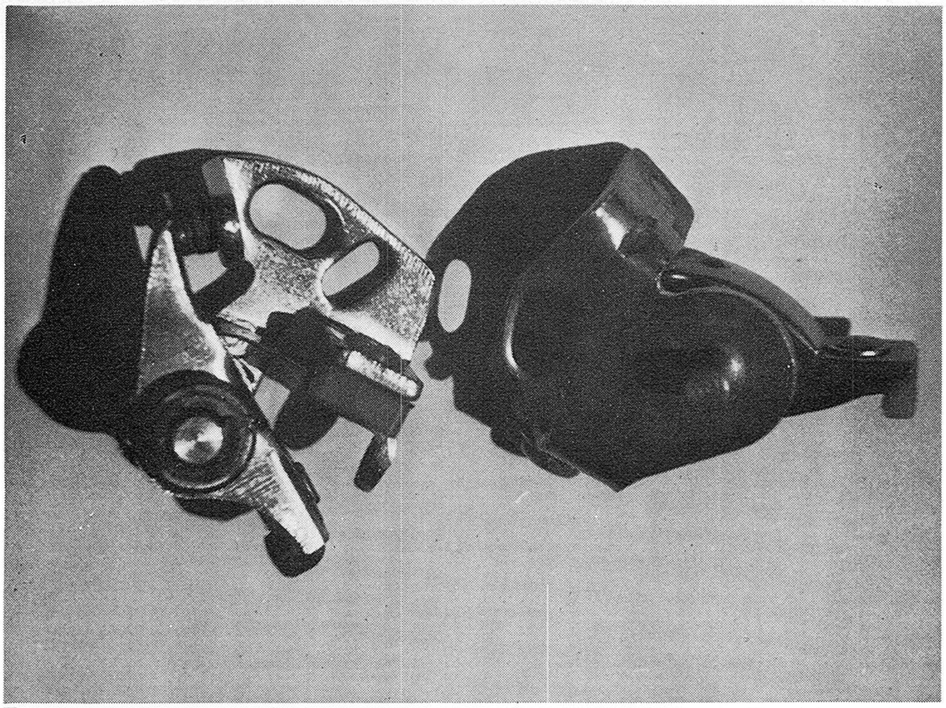
The reason the point set is arranged to be adjustable, independent of the stator setting is, first, to allow setting the point gap to spec. Then, during normal engine operation, the fiber rubbing block on the point set will gradually wear away. After a time, it will be necessary to reposition the point assembly to restore the point gap dimension.

The specification of point gap, fundamentally, is simply a handy way to say where the points are opened by the cam. The actual point gap is not as important as ignition timing, as long as there is enough point opening to positively interrupt current flow.

Many manufacturers allow a range of point-gap value in the ignition specs. The object is to find a gap setting, within that range, which gives proper ignition timing.

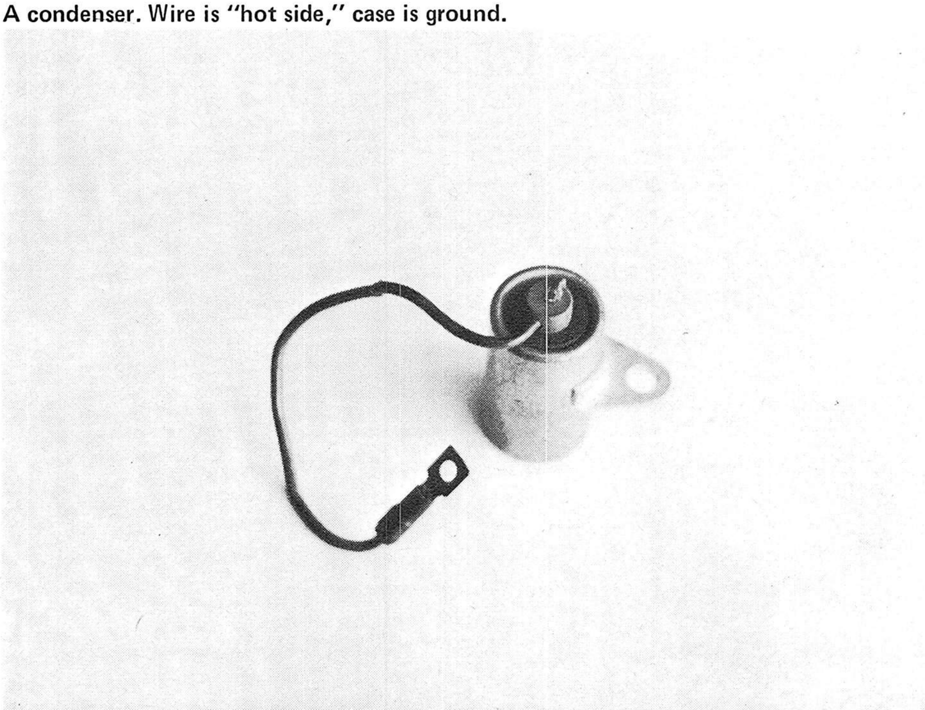


Stator plate mounts point set at bottom, condenser at top, ignition coil at left, lighting coil at right. Electrical wires have been pulled through center hole for convenience in taking the photo—normally they stay behind the stator and are routed out of the engine case to electrical parts on bike. An extension of the crankshaft passes through center hole of stator, flywheel mounts on end of crank. Notice that the pole-pieces for the two coils are shaped to match the shape of the inside of the flywheel. Just below condenser is a felt pad held by a metal clip. This pad is lubricated, wipes on cam which is part of flywheel, cam operates against the fiber rubbing block (arrow) on the movable arm of the point set. Purpose of lubrication via felt wick is not to preserve the metal cam, it is to preserve the relatively soft fiber rubbing block. You will go longer between ignition timing adjustments if you put a drop of oil on this felt wick every time you have access to it.



Two point sets, one upside down to show mounting stud on bottom. Movable point-arm is insulated from its pivot by fiber bushing and fiber washers top and bottom. Stationary point is grounded because it is clamped against the stator.

A condenser. Wire is "hot side," case is ground.



Assume we have done this. We have loosened the holding-screw for the points and adjusted gap setting until the gap is within tolerance and the spark timing is right on. We button it up and ride the bike a while.

As the rubbing block wears away, the point gap gradually gets smaller and the ignition timing gradually becomes retarded. One day we notice that the machine is in poor health.

We take it apart and, sure enough, timing is retarded. We fiddle with the gap settings again and discover that there is no gap within permissible limits which will give the correct ignition timing. This is because the fiber rubbing block is worn considerably.

The problem is that when the worn point set is rotated toward the cam far enough so that the points open at the proper time, the rubbing block engages the cam much lower down on the cam profile. The result is that the points are opened more than the specification will allow, due to the changed geometry between point set and cam.

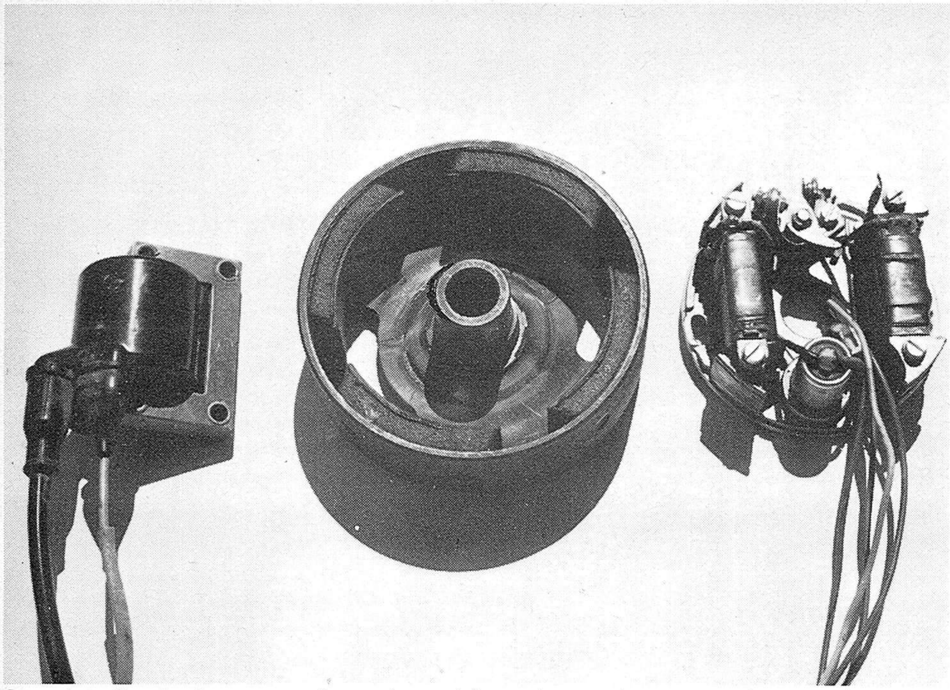
The timing was set right by changing the point gap, but the point gap is now too large. What to do?

Remembering that rotation of the stator plate influences timing, we pull off the flywheel, loosen the stator, and rotate it to move the entire point assembly closer to the cam by an amount approximately equal to the amount of rubbing-block wear. Then, we can find a point-gap setting within limits which also provides the correct ignition timing.

Does this solve the problem? When you are watching your favorite detective on TV, you can look at your wristwatch and see how much time he has left to undo the bad guys. Similarly, because you see more paragraphs below, you can conclude that we did not solve the problem yet.

The bike doesn't run well. Everything seems to be in good shape. The cam on the flywheel is knocking the points open the right amount, and at the right time. But, the engine misses under load.

The difference between the set-up this time, and the last time the ignition timing was adjusted, is rotation of the stator plate to compensate for rubbing-block wear. Since both points and source coil are



Complete flywheel magneto. Stator is on right, points at the top, condenser at bottom. Flywheel in center, magnets around periphery. If you look closely, you can see that the hub is shaped as a cam, with the lobe to the left. Spark coil is at far left.

mounted on the stator, the source coil has been moved also.

If the timing is right, this means that the spark is happening when the flywheel is at the correct angle. The magnets in the flywheel are at the same location as they were before, when the spark occurs. But, the source coil is at a different location.

As you remember, one of the original goals was to open the points when the voltage in the source coil was high, and this occurs when the magnet is at the right place in its journey past the coil. When we move the coil, we raise the possibility that the points may be opening when the coil voltage is lower than maximum.

To solve this problem, many manufacturers give another specification, which is the distance from some point on a magnet to some point on the source coil at the instant the points open. If the stator has been rotated too much, this dimension will tell you so, if you can figure out a way to measure it. Measurement is not easy because the parts are on the inside of the flywheel whereas you and your ruler are on the outside.

As a practical matter, the electrical points will usually erode and cause problems before the rubbing block wears away enough to affect the magnet-coil relationship seriously. Typically, you can reset timing with the stator plate two or three times, each time cleaning the points or resurfacing them with a fine-tooth file, and then you will prudently replace the points.

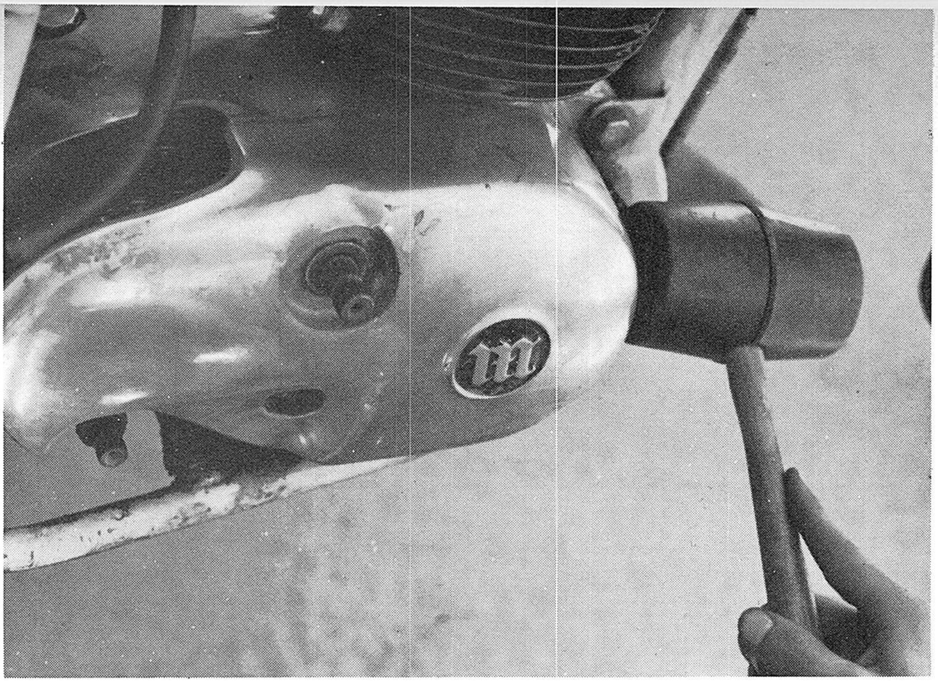
Every ardent tuner, when confronted with a problem that he cannot solve intellectually, becomes an ardent parts changer. If you manage to adjust the stator so far that it causes a weak spark, you will eventually replace the points while trying to solve the problem. That will fix it.

THE PRACTICAL WAY

Once you understand all of the above, you can set point timing by a relatively simple procedure.

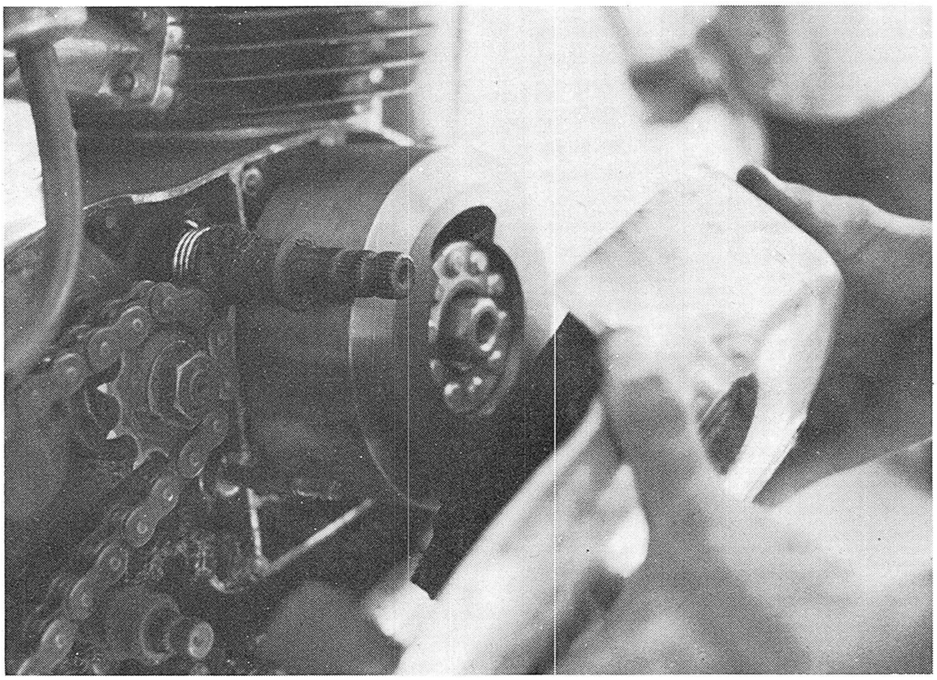
1. Set point gap to spec.
2. Rotate the stator until ignition timing is correct.

From the correct setting (however you find it) wear of the rubbing block will cause timing to become progressively worse in the retard direction. If the engine will tolerate timing which is a little bit advanced from the correct value, then the initial wear will improve performance by gradually retarding the spark to the correct value. Further wear will then degrade performance. The average performance will be better over a period of time if timing is set for a slight extra advance than it will be if timing is set spot-on. However, the engine must tolerate this extra advance without heating or hurting itself.

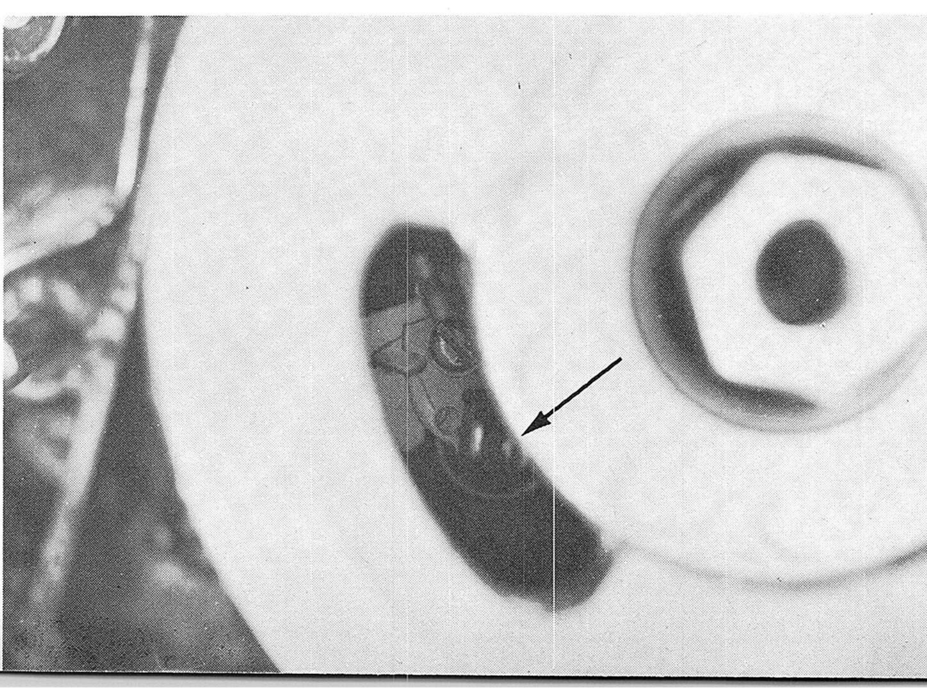


Journey To The Innards Of A Flywheel Magneto

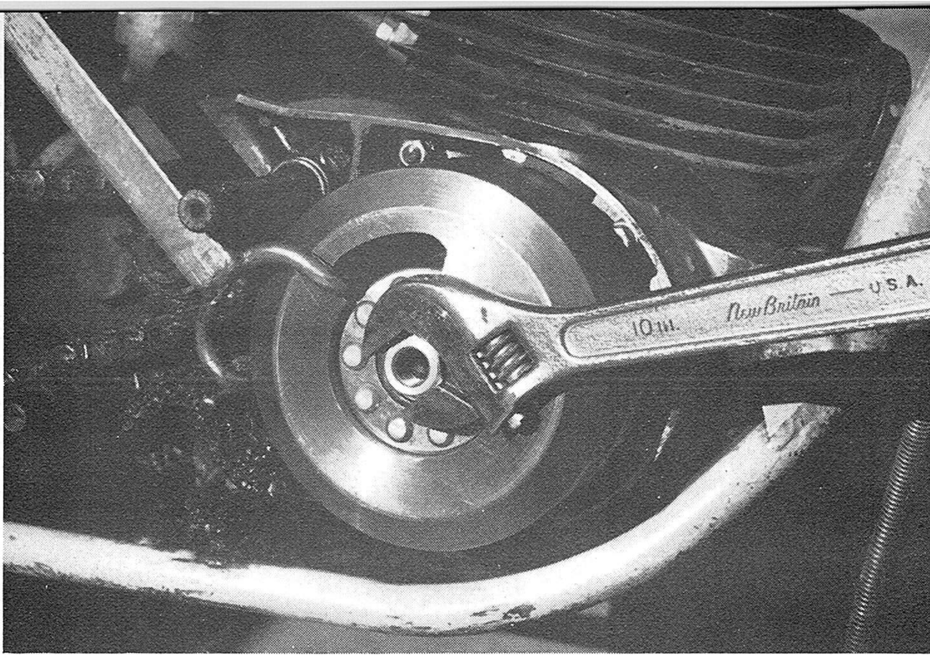
Kick-starter, gear lever, and case screws have been removed. Flywheel magneto lives inside this side cover. Rubber mallet is used, gently, to start removing side cover. As it happened, the carb was off this bike, and fuel line is laying down on the chain. Not a part of this procedure.



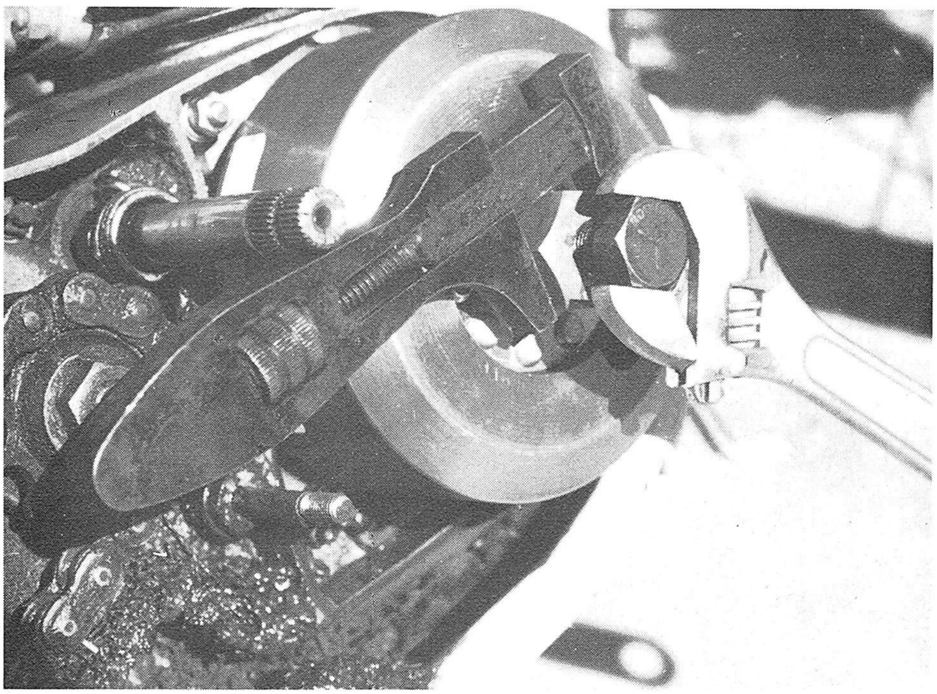
Cover is removed, exposing flywheel, goo from chain lubricant, kick-starter return spring, and drive sprocket. Fuel line is still there.



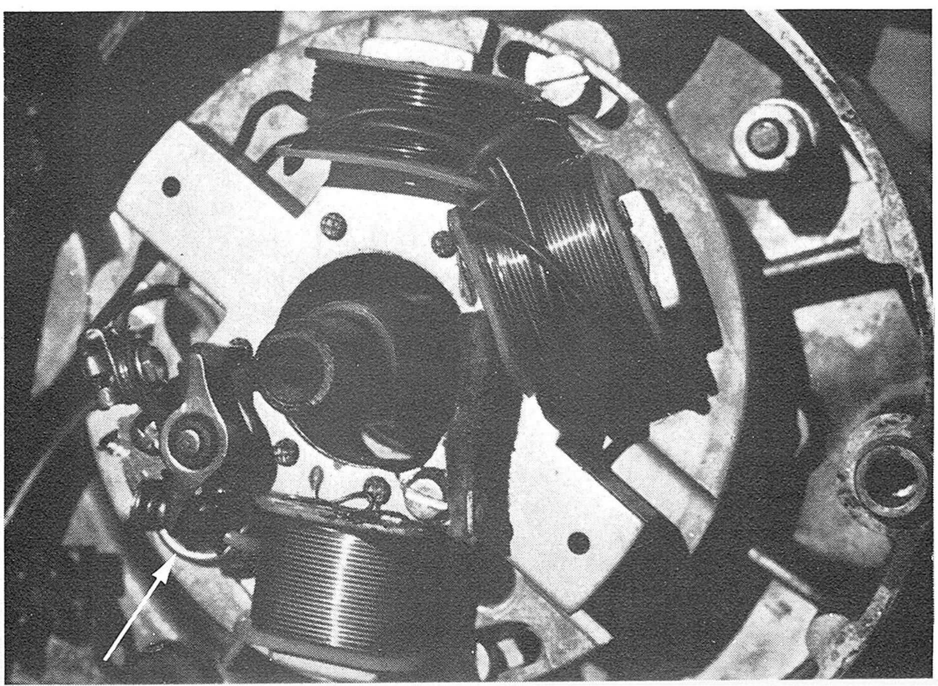
Through crafty photography, the only part of this picture which is in focus is the point set, visible through the hole in the flywheel. To set point gap, it is not necessary to remove flywheel, you work through the hole. Points are barely visible at the bottom. Screw loosens point-set for adjustment. V-shaped notch on points and notch on stator plate provide means of adjustment. You put a screwdriver blade in the notches and twist. Sometimes you can get proper timing this way.



If not, you have to remove the flywheel. Start by taking off the nut on the end of the crankshaft. Flywheel holder, braced against kick-start shaft, holds flywheel while nut is removed.
This is a left-hand thread on some bikes.
This is a left-hand thread on some bikes.
This is a left-hand . . . ! !



Then, screw a flywheel puller into the hub of the flywheel and, with two wrenches, wrench the thing off. Never use any other kind of puller. Never hammer or pry on the flywheel.



With the flywheel removed, there are the coils and points, mounted on the stator plate. The condenser is barely visible (arrow) behind the points. The fiber rubbing block, on the operating arm of the point-set, is now pointing toward the end of the crankshaft. When the flywheel is in place, a cam on its inner surface engages the rubbing block and opens the points. Directly opposite the points is a felt wick which lubricates the ignition cam, if you put a small amount of oil or grease on the wick. The stator plate is held in place by three screws in elongated slots.

MULTI-CYLINDERS

There is a great variety of possible combinations among the following:

- 1, 2, 3, 4 or more cylinders
- Single-throw crankshafts
- Two-throw crankshafts at 180 degrees, or 90 degrees, or some other angle.
- Three-throw crankshafts at 120 degrees
- Ignition driven at engine speed or one-half speed.

Many of the possible combinations of the above can be found in the variety of motorcycles available today.

On the surface, these combinations produce complex ignitions, sometimes with multiple point-sets, multiple cam lobes, multiple or two-headed coils, or sometimes automotive-type ignition distributors.

Any system becomes less complicated if it is viewed simply as some scheme which gets one spark to each cylinder at the proper instant. With this point of view, and recourse to the manual for a particular bike, understanding the ignition system is straightforward.

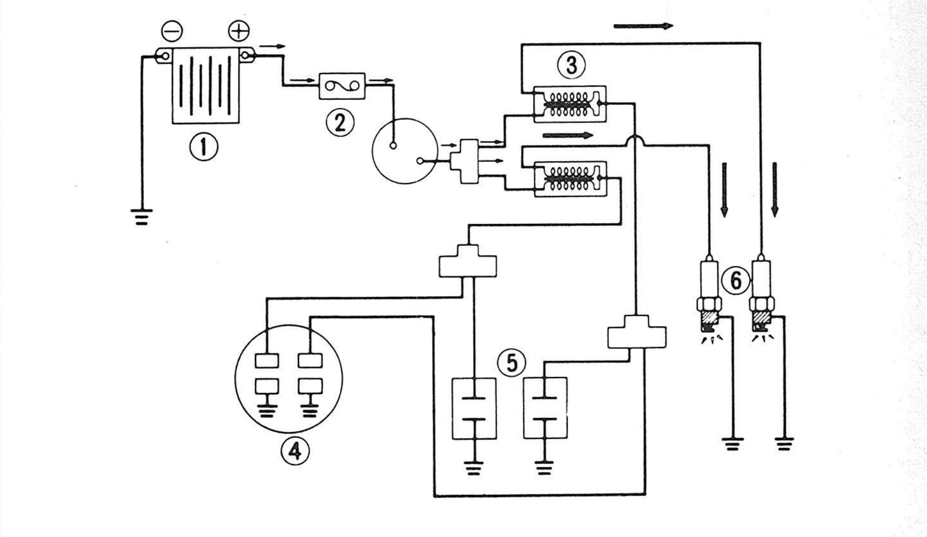
There is one aspect of ignition timing on multi-cylinder engines that is worth further mention. It is the problem that there is normally only one stator. If the stator is adjusted, rotationally, for proper time on one cylinder, it cannot be readjusted then to time other cylinders. Timing the other cylinders is then done by changing the point gap of the mechanical points which serve the other cylinders (or equivalent).

A vertical twin may have a single-throw crank, causing the pistons to travel up and down together. It may fire the cylinders alternately, or both at the same time.

For a vertical twin four-stroke with a 180° crank, the cylinders will fire alternately. If the ignition is driven at crank speed, this will require two sets of points, 180° apart, on the stator.

If the ignition is driven at half-speed, the points will be at 90°.

Wherever the points are located, the ignition pulses are not spaced evenly in time, as shown by the timing diagram. Typically, on a four-stroke twin with battery-coil ignition, there will be two separate ignition systems with nearly all the parts duplicated, as shown in the wiring diagram.

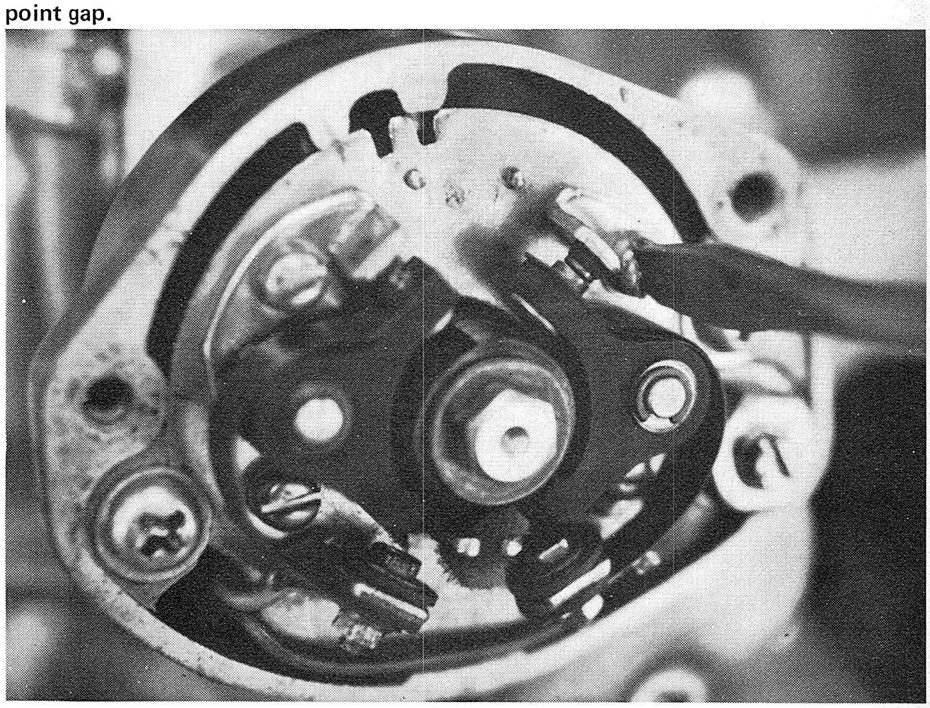


WIRING DIAGRAM—FOR BATTERY-COIL TWIN IGNITION

Wiring diagram for battery-coil twin ignition.

1 – Battery
2 – Fuse
3 – Twin coil
4 – Points
5 – Condensers
6 – Spark plugs

Ignition cam and points for diagram above. Cam is half-speed, so rubbing blocks are 90° apart. Screwdriver shown adjusting point gap.



In the photo of the two breaker points, the ignition cam is driven at half-speed. Assume that each set of points has been adjusted for proper point gap. This is done by rotating the engine until each point set is held open by the cam and then rotating the point set for proper gap.

The timing is then checked for the set of points which fires the left-hand cylinder. The timing is not correct, so the stator plate is loosened and rotated until timing is correct, for the left-hand cylinder.

If the tuner is lucky, this position of the stator will also provide correct timing for the right-hand cylinder. However, if it is not correct, timing may not be adjusted by rotating the stator plate again, because that would destroy the setting made earlier for the left-hand cylinder.

The only choice is to adjust timing for the right-hand cylinder by varying the gap of the point set which fires that cylinder.

If correct timing for the right-hand cylinder cannot be found within the permissible range of gap settings, the tuner has a problem. This can sometimes be solved by starting all over again and "fudging" the gap on the left-hand point set. Or, it may require two new sets of points.

A greater range of adjustment can be provided by using a different method of mounting the right-hand point set. This requires a base plate between the point set and the stator. The point assembly is mounted on the base plate and the base plate is then mounted on the stator.

The object is to create an additional, independent adjustment for the right-hand points. These points may then be rotated on their base plate, for point gap, and then the base plate may be moved on the stator for timing the right-hand cylinder.

The next level of complexity is to put both point sets on individual base plates. The two base plates mount on the stator. Each individual base plate is moved to time the associated cylinder and the stator is not moved at all as a normal tuning adjustment.

The main problem with these three methods is nomenclature. Different manuals use different names for the various parts. You can read about point-plates, base-plates, breaker-plates,

FIRING ORDER OF 4-STROKE ALTERNATE-FIRING VERTICAL TWIN WITH 180° CRANK

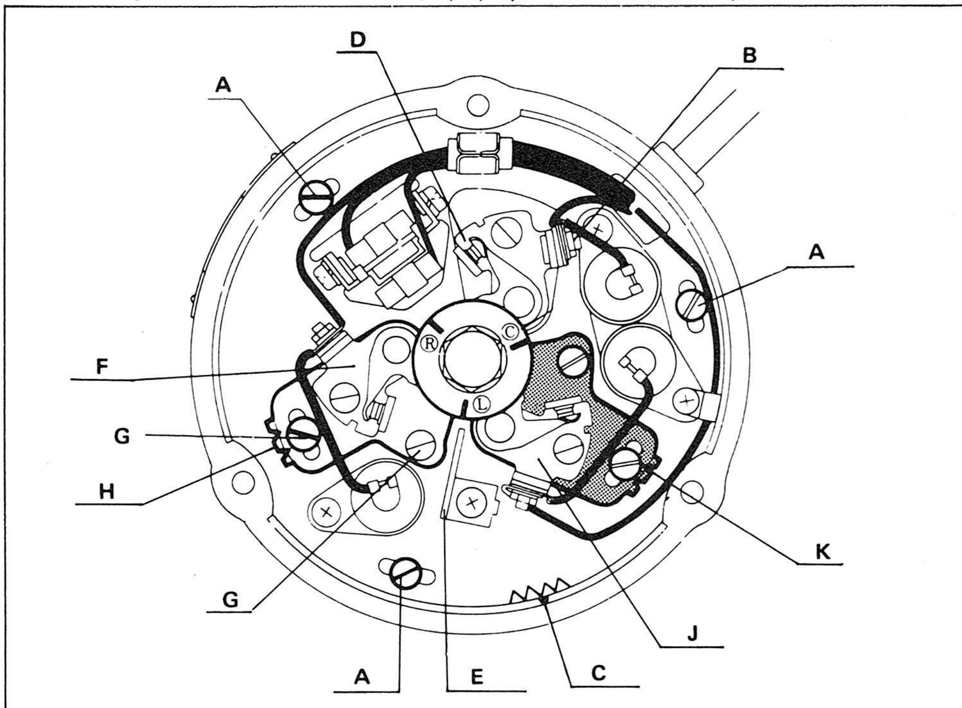
Cylinder	#2	#1	#2	#1	#2	#1	#2	#1	#2	#1	#2	#1
Stroke	I	C	C	P	P	E	E	I	I	C	C	P
Firing Point		F	F							F	F	
Degrees on Crank	180°		180°		180°		180°		180°		180°	
Degrees on Camshaft	90°		90°		90°		90°		90°		90°	

Firing interval on crankshaft is 360° per cylinder:
#1 to #2 is 180° #2 to #1 is 540°

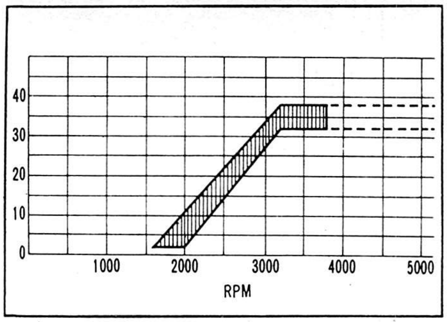
Firing interval on camshaft is 180° per cylinder:
#1 to #2 is 90° #2 to #1 is 270°

I — Intake Stroke
C — Compression
P — Power Stroke
E — Exhaust Stroke
F — Spark Plug Fires

This drawing shows breaker-point ignition as used on some models of the three-cylinder Kawasaki. The three point-sets are D, J and F. D is mounted to the stator plate which is mounted to the engine by three screws, all labeled A. When screws, A, are loosened, stator can be rotated using screwdriver in notches C. This times one cylinder.
Breaker-points J and F are mounted on individual baseplates K and H, outlined for emphasis. This allows timing the other two cylinders by loosening screw G and its counterpart, using a screwdriver in the notches adjacent to the holding screws.
Point gap is set individually for each point set by loosening the clamp screw on each and using screwdriver in adjacent notch.
This arrangement allows both proper timing and proper point gap for each cylinder.
Pointer E registers with marks on rotor, C, L, R, to indicate which cylinder should fire.



3-CYLINDER BREAKER-POINT IGNITION



IGNITION ADVANCE CURVE

stator-plates, ignition plates, as well as anonymous bases and plates, until you achieve any desired amount of confusion.

On a particular motorcycle, you can look at the parts in terms of function, and it is easy to see what they do.

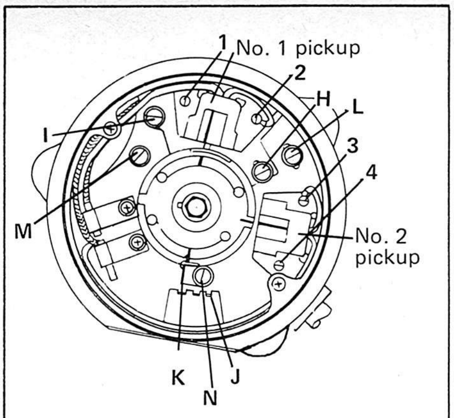
ADVANCE MECHANISM

All of the systems and methods discussed so far produce an ignition timing which is fixed and remains the same at any engine speed. Some motorcycles introduce the refinement of a centrifugal advance mechanism which will increase spark advance, as RPM increases, achieving full advance at around 2,000 or 3,000 RPM. From there on up, advance is fixed.

The advance mechanism can be considered as an add-on to the mechanisms already discussed, which generally rotates the ignition cam in respect to the crankshaft.

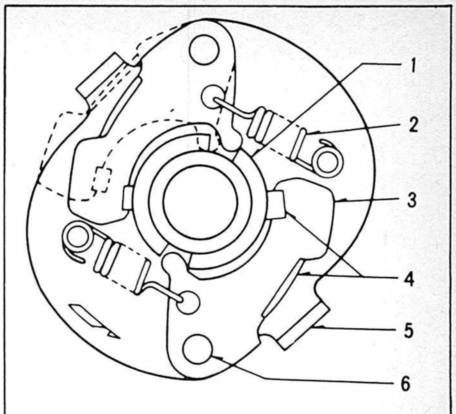
The principle is to separate the cam, mechanically, from the crankshaft by interposing the advance mechanism.

The specifications for a centrifugally-advanced ignition will include static timing, which is the spark timing when the engine is not running, or is running so slowly that the advance mechanism has not started to function. It will also include the amount of advance which should be added by the centrifugal ad-



ELECTRONIC IGNITION

Electronic ignition for two-cylinder Kawasaki is timed like any other ignition, when parts are examined for function.
Pickup coils 1 and 2 generate trigger pulse for electronic switch in ignition circuit, by sensing magnet in rotor.
Pickup coils are attached by screws 1, 2, 3 and 4. These screws are loosened only to adjust air gap between end of pickups and rotor.
No. 2 pickup mounts directly on stator.
No. 1 pickup mounts on baseplate which, in turn, mounts on stator, held by screws I and H.
Stator is held by screws M, L and N. When loosened, stator may be rotated using screwdriver in notches, J. This times no. 2 pickup.
Pickup no. 1 is then timed by loosening screws H and I and moving the baseplate in respect to the stator.
Pointer K aligns with marks on rotor to indicate piston position. Position of K is first set by using a dial indicator in spark plug hole and can then be used as timing reference.



IGNITION ADVANCE MECHANISM

Spark advancer
1 — Breaker cam
2 — Governor spring
3 — Governor weight
4 — Rubber
5 — Stopper
6 — Governor weight pivot

In this drawing of a centrifugal advance mechanism, the entire assembly rotates counterclockwise, as shown by the arrow. Two weights, operating on pivots, 6, move outwards as RPM increases, shown by dotted line in full-advance position. Springs, 2, oppose outward movement and return weights to rest position when RPM is low. Rounded tang on each weight, near spring attachment, fits into groove on breaker cam, 1. As weight moves outward, tang in groove rotates breaker cam counterclockwise in respect to crankshaft. This causes cam to open points earlier and produces advanced ignition timing. Maximum advance is limited by stops, 5, which limit outward travel of weights.
Rate of spark advance, with RPM, is governed by governor weight and stiffness of springs.

vancer and the RPM at which the automatic advance should commence, and the RPM at which it should be all in. It is handy to show this information by a graph, or spark-advance curve.

Values may be something like 10 degrees static advance and 40 degrees total advance. In this case, the automatic advance contributes 30 degrees between full out and full in.

If the above spec is in terms of crankshaft degrees, then the same timing measured at half-speed on the valve train would be 5 degrees static and 20 degrees total.

Static timing is set by rotating the stator, and then the advance is checked. In some cases, there will be a reference mark on a flywheel to show static timing and another to show fully advanced timing. The full advance can be checked, when the engine is not running, by operating the advance mechanism manually. This does not guarantee that amount of advance when the engine is actually running.

The best way to check this timing is with a strobe light, as described in section seven.

If the amount of centrifugal advance is not correct, or if it does not happen at the correct RPM, the problem will be in the advance mechanism. This can be weak springs, a sticking pivot, improper weights or some combination.

OBSERVING TIMING

The intent of this section was to give you an idea of the types of ignitions, what the parts do, what the adjustments are, and what happens when you make an adjustment.

It is apparent that, in order to set timing, you have to know two things:

1. Where the timing is, and
2. Where it should be.

We have talked about where it should be and the use of reference marks or piston position as an indicator of the proper spark timing.

To determine where the spark is actually happening, we have used words like "observe the points opening," which is not as easy as it sounds.

The measurement of spark timing, by several practical ways, is gathered up with the measurement of the other tuning variables and they are all discussed together in section seven.

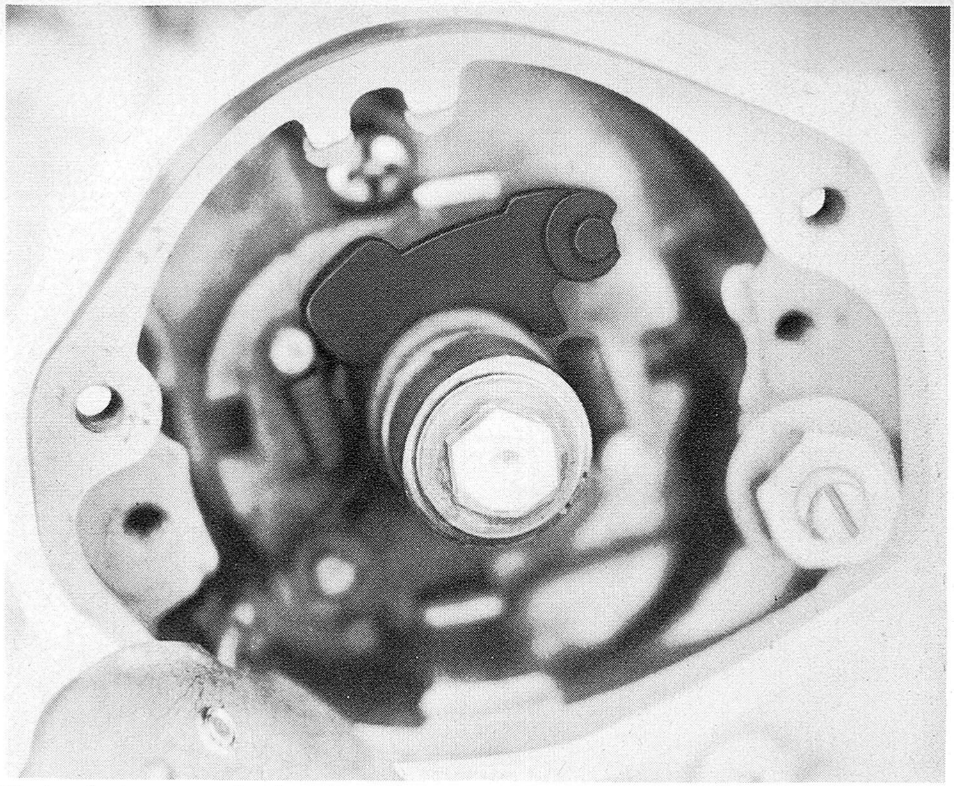


Photo of advance mechanism shown in drawing on preceding page. Governor weight rotates on pivot as RPM increases.

No substitute for experience? That's right. However, you don't have to wait around for experience to happen to you. If you do, it will probably be mainly bad.

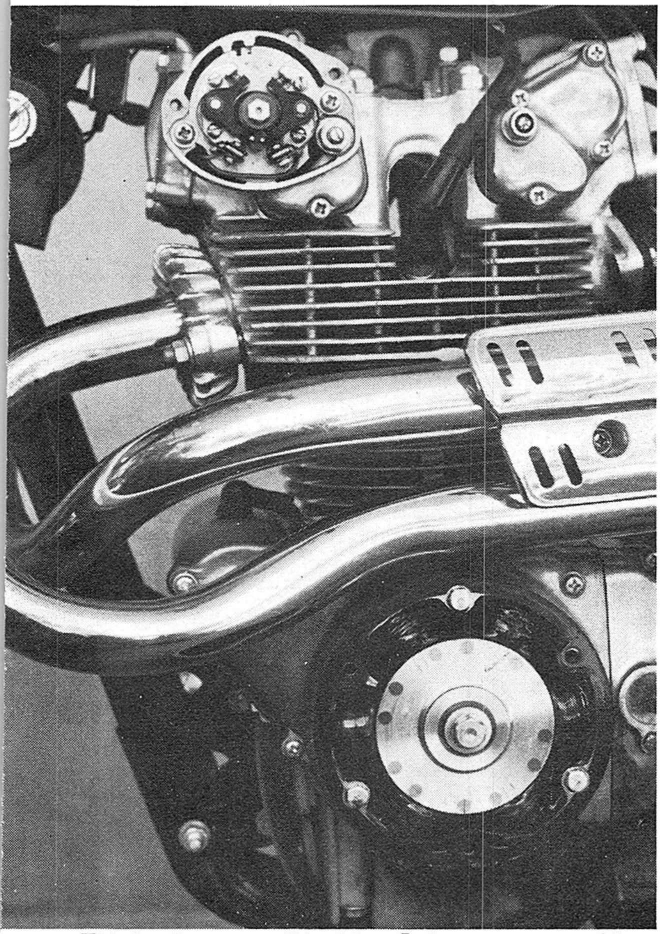
I remember once I was having problems with an engine. (It happened to be a four-wheeled racer.) I smartly decided to whip out a plug and take a look at it. Which I did. Then I said to myself, "I wonder how this thing is supposed to look."

After that, I looked at plugs at every opportunity. I would take a plug out of a good-running engine to see what it looked like. I looked at plugs out of sick engines, other people's engines, and even plugs in the trash. Now, I think I know what they are supposed to look like.

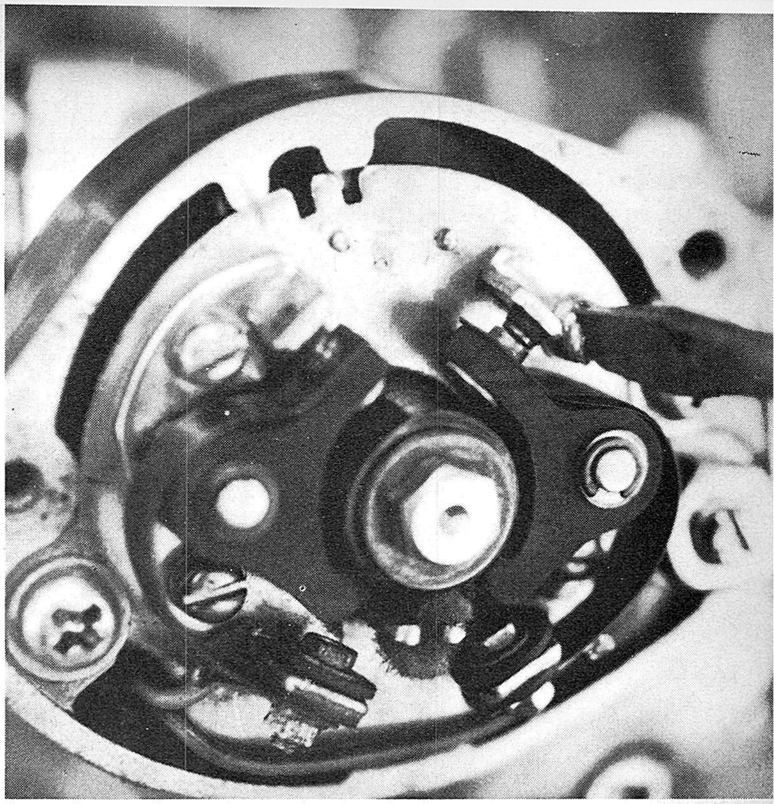
In the last section, we talk about a bike sounding rich and acting rich. There is no way to tell you what that is like. You can gain the experience very easily. Make your bike rich and ride it for five minutes. Then, you have the experience.

A very poor reason for not doing something is to say that you have never done it before. If you really meant that, you would still be in the cradle, receiving food in a rather undignified way.

Honda 450 Timing

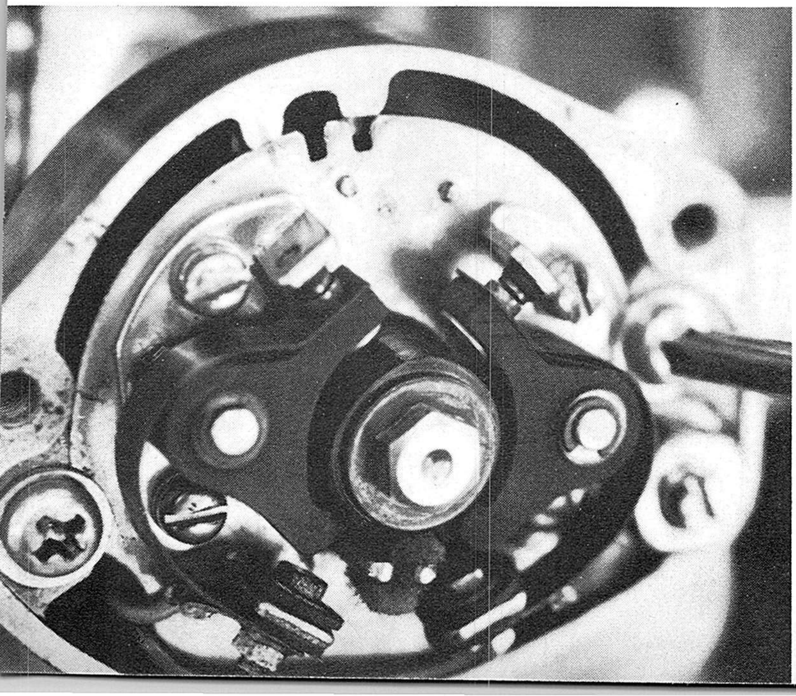


This is a battery-coil ignition. Points are operated by the valve train at half speed. Timing marks are on the rotor of the generator, on the end of the crankshaft, turning at full speed of the engine. Timing marks on the rotor are 180° apart for the two cylinders. This corresponds to the 90° spacing of the points on account of the speed difference of the two shafts.

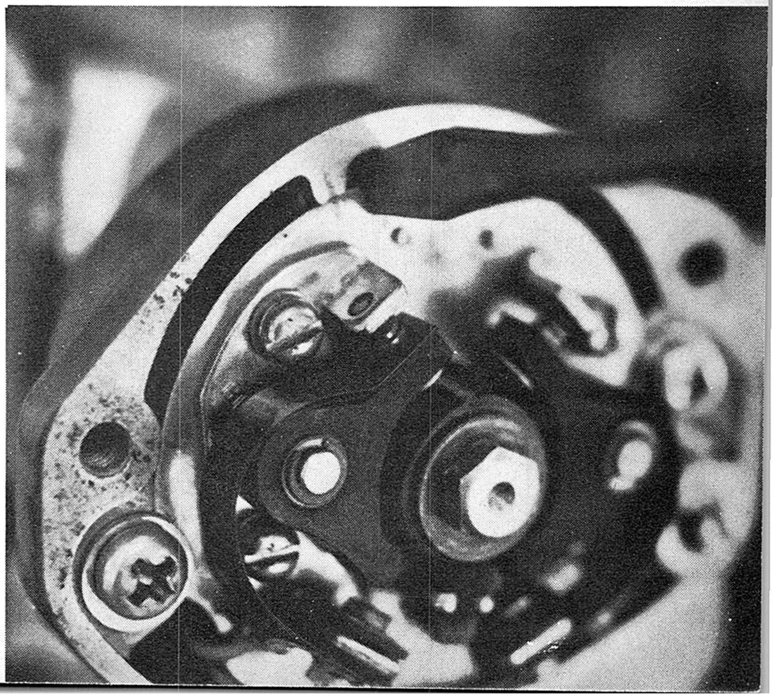


Set point gap for each set of points by loosening screws which attach breaker assembly to stator of ignition.

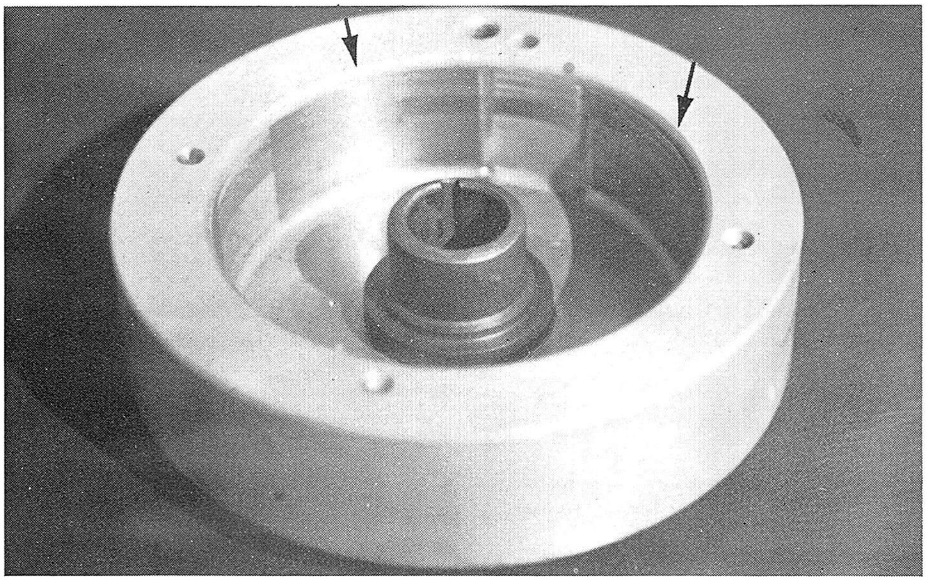
Loosen cross-head screws holding ignition stator.



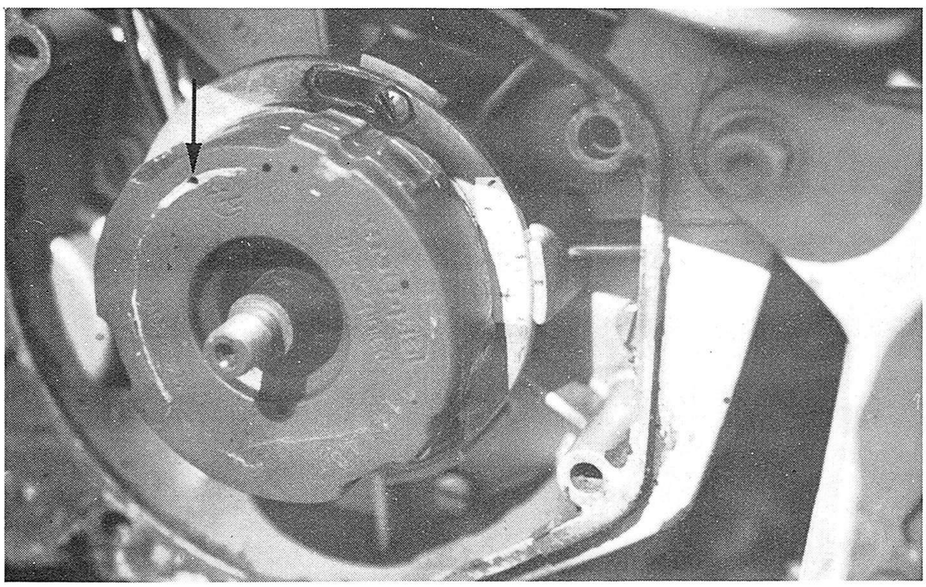
Use screwdriver in notches at top of stator and rotate for correct timing of the left-hand cylinder. Reset gap of the points which serve the right-hand cylinder to get proper spark timing for the right-hand cylinder.



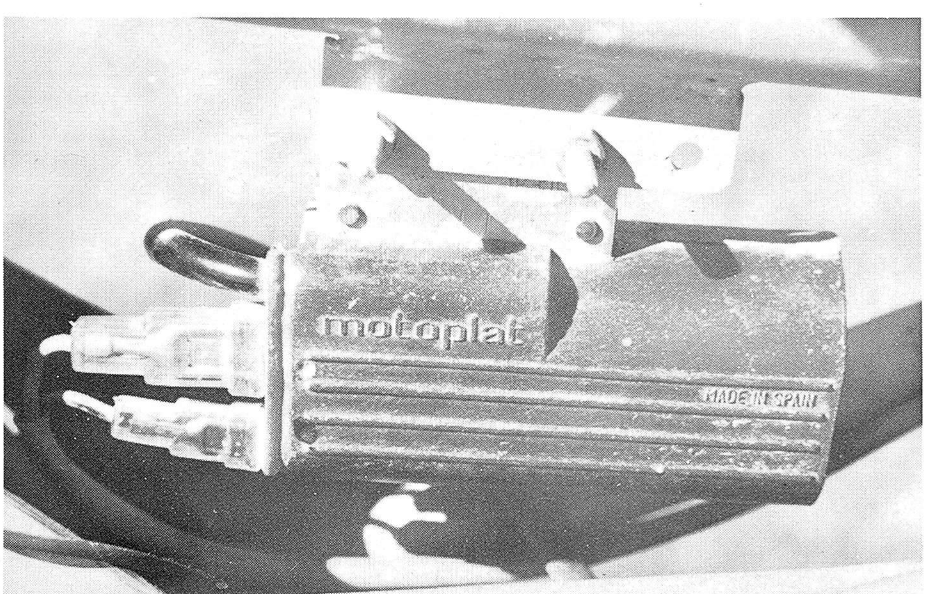
Electronic Flywheel Magneto



The flywheel fits on the end of the crankshaft and is located by a key. The keyway is in the hub of the flywheel. The dark areas on the perimeter are the magnets (arrows) cast into the metal of the flywheel.



All of the "works" are encapsulated and mounted on the stator plate. Stock timing, with this setup is achieved by pushing a wire through a hole in the flywheel and feeling for a mating hole on the stator. The scratches on the stator were caused by feeling around with the wire. The hole where the wire goes is identified by heavy scratching on both sides. Performance tuning is done using the homemade scale, stuck onto the stator plate and referenced to the mark on the case. This end of the crankshaft rotates clockwise. As you can see by the elongated slots in the stator, the timing is fully advanced.



The remainder of the ignition system is encapsulated with the coil and hangs on the frame, under the gas tank.

COMPRESSION

One of the major developments which improved internal combustion engines was the realization by early builders that the work output could be increased by compressing the mixture before igniting it. This section discusses that idea, conceptually, along with a minor excursion into arithmetic.

It also discusses:

- How compression occurs in an engine.
- Compression ratios.
- Primary and secondary compression in a two-stroke.
- Related matters.

MECHANICAL

The peak cylinder pressure of an engine is limited by detonation and the quality of fuel available, plus tuning factors. The peak pressure is composed of two parts. Initially, there is mechanical compression of the mixture. Following this, there is additional pressure due to the heat of combustion.

When compression of the mixture is less, power is less. That is probably the most important message in what follows.

The pressure increase due to heat is a function of the starting temperature and the ending temperature. This temperature ratio results in a multiplying factor which is applied to the pressure that existed prior to the temperature increase.

Assume that a mixture is mechanically compressed to 40 psi, and then a temperature change multiplies that by five. The result is a peak pressure of 200 psi which can then do work on the piston, forcing it downwards in the bore.

If the compression is increased to 60 psi, the peak pressure will rise to 300 psi.

It took more energy *from* the crankshaft to compress the mixture to the higher figure, after which the mixture delivered more work *back to* the crankshaft during the power stroke. If the latter is more than the former, then there is a bonus in thermal efficiency.

The additional work in compression was an extra 20 psi achieved during the upstroke of the piston.

The additional work delivered was an extra 100 psi, effective during the downstroke of the piston.

The net work output was increased. The discussion above is an oversimplification, and the effects are non-linear, however that is the general idea of compression.

TEMPERATURE RATIO

An idea of the pressure increase due to temperature can be obtained from our friend, the ideal gas law, which can be written

$$P = \frac{KT}{V}$$

and simplified to

$$P \sim \frac{T}{V}$$

If we wish to compare two pressures, we can write two equations and divide them.

$$\frac{P_2 \sim \frac{T_2}{V}}{P_1 \sim \frac{T_1}{V}}$$

Most of the burning takes place while the piston is near TDC. If we assume that the volume does not change while the temperature is increasing, then we can eliminate V in the expression above.

$$\frac{P_2}{P_1} \sim \frac{T_2}{T_1}$$

or,

$$P_2 \sim P_1 \times \frac{T_2}{T_1}$$

This says that the ratio of temperatures is the multiplying factor, by which the original pressure is multiplied to get the final pressure. In the real world, the temperature ratio is an approximation of the pressure ratio because the equation above assumes that all of the temperature-energy goes into increased pressure-energy which does not happen. Some of the temperature-energy is wasted by heating up the engine and in the elevated temperature of the exhaust. Also, the volume in the combustion space does not remain exactly constant during burning.

COMPRESSION RATIO

An idea of the change in pressure due to mechanical compression by the piston can be obtained by recognizing that this is basically a change in volume. The ideal gas law can be jiggled around to say

$$P_2 \sim P_1 \times \frac{V_1}{V_2}$$

$$T = K$$

which says that, if temperature is constant, a decrease in volume results in an increase in pressure.

The fraction V_1/V_2 is called the compression ratio of an engine and is simply the largest volume in the cylinder (BDC) divided by the smallest volume in the cylinder (TDC).

When the piston is at the top of its stroke, the remaining volume in the cylinder is that of the combustion space, V_c. When the piston is at the bottom of its stroke, the volume in the cylinder has been increased by the displacement of the piston.

Therefore, the compression ratio, CR, is simply

$$CR = \frac{V_c + \text{Displacement}}{\text{Displacement}}$$

Displacement is, of course, the area of the top of the piston (or a section through the cylinder) multipled by the stroke. It is a volume and is, theoretically, the amount of gas displaced by the piston as it moves from top to bottom or vice versa.

COMPRESSION PRESSURE

The *actual* compression pressure is usually different than the compression ratio would indicate. However, let's use the CR as though it were purest truth, for a minute.

If an engine has a CR of 10:1, and breathes in a cylinder full of outside air at 15 psi, then the CR suggests that the pressure in the cylinder at TDC will be 150 psi, assuming the mixture is not ignited.

The reasons it may be different than that are several. If, due to volumetric efficiency, the pressure in the engine, at the end of the intake event, was less than atmospheric, then the pressure rise will not be atmospheric multiplied by the CR.

If an engine breathes exceptionally well and has a high order of inlet and exhaust tuning, the pressure at the end of the inlet event can exceed that of outside air, *over a small range of RPM.* In that case compression pressure would exceed the calculation above.

If the gas leaks out while being compressed, the final pressure will obviously be reduced. Leakage can occur through valves or ports which are imperfectly closed, past the piston rings, and past gaskets or joint seals which are defective.

GEOMETRIC OR ACTUAL

When CR is figured by use of displacement and combustion volume, no consideration is paid to the fact that there may be valves or ports open during the time when the piston is assumed to be compressing the mixture. The CR becomes a simple geometric comparison of two volumes.

It is usual to have valves or ports open during part of the compression stroke of the piston. It can be assumed that actual compression cannot begin until all openings into the cylinder are closed.

Four-stroke engines are typically specified by the "geometric" CR.

For two-strokes, there are two customs. Some manufacturers state the geometric CR. Others use "effective" or "actual" CR, which is calculated by measuring the travel of the piston *after* the transfer and exhaust ports have been closed.

TWO-STROKE PRIMARY

Two-strokes have two compression events, one in the crankcase and the other above the piston. Mixture is drawn into the case by the upward travel of the piston while the top side of the piston is compressing a prior charge of fuel-air. On the following downstroke the inlet port is closed, the transfer port opened, and the downward movement of the piston forces fuel-air up through the transfer passages into the cylinder.

The case compression can also be thought of as geometric or actual. Well-designed two-strokes seldom have a crankcase volume much smaller than about two times the displacement, therefore geometric CR runs around 1.5 to 1.

Actual compression will be less than this because ports are open during part of the stroke, and actual compression may run around 1.3 or so.

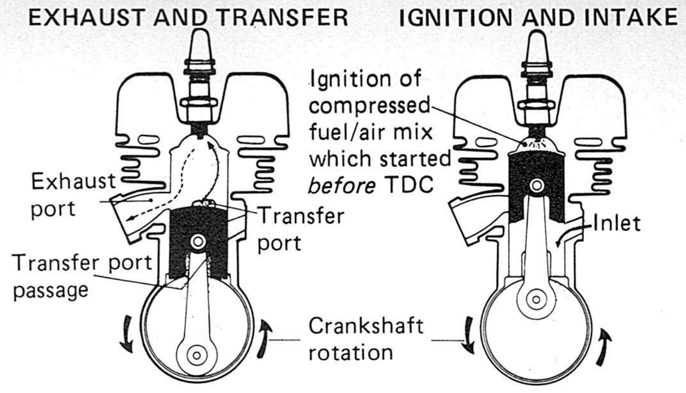
When the mixture has been transferred to the space above the piston, the pressure in the cylinder (prior to cylinder compression) can be no higher than was the pressure in the case at the end of the inlet period. It will be less than case pressure due to friction losses in the transfer passages, pumping losses, and the combustion volume in the head.

This can be visualized by considering that the ports open instantly, while thinking through one transfer event. Prior to transfer, with the piston at the top, assume that the case filled up to atmospheric pressure. Now, with all ports closed, imagine the piston is moved to BDC. The case pressure is increased because the volume which contains the gas has been reduced by the *displacement* of the piston.

Imagine, now, that the transfer ports are opened suddenly. This adds volume into which the gas can now expand. The volume added is the *displacement* of the piston, plus the volume of the combustion space above the piston.

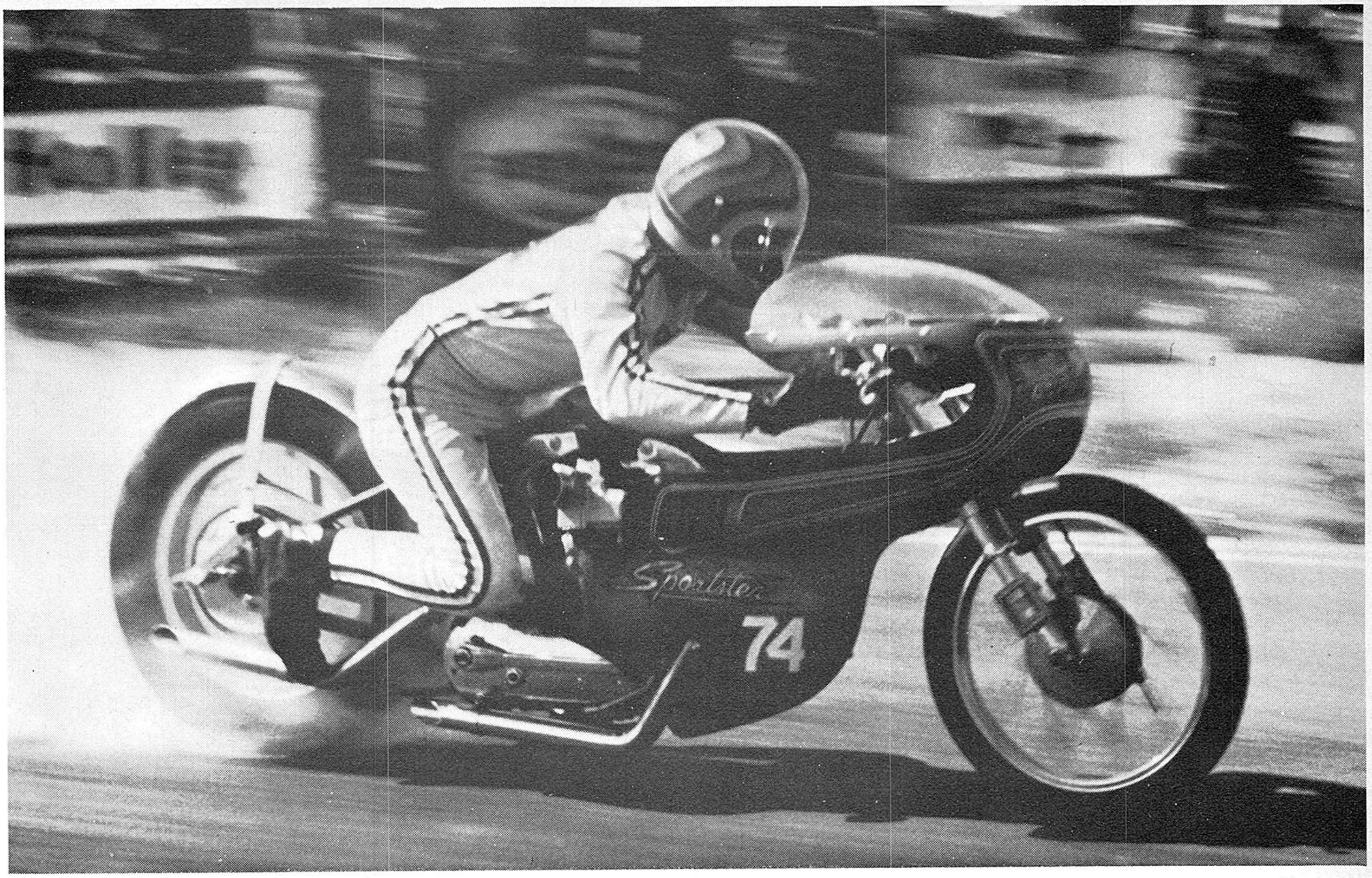
If the volume added by opening the transfer ports were exactly the displacement of the piston, the gas pressure would return to atmospheric, as it was before it was compressed. However, the added volume is slightly more than the displacement of the piston, so the cylinder pressure at the end of the transfer event is slightly lower than was the case pressure at the end of the intake period.

Case compression in a two-stroke does not contribute to compression in the cylinder above the piston. It is all "used up" in pumping the mixture up through the transfer ports. If some of the compressed mixture leaks out through bad crank seals or somewhere, then that mixture will never make it upstairs.



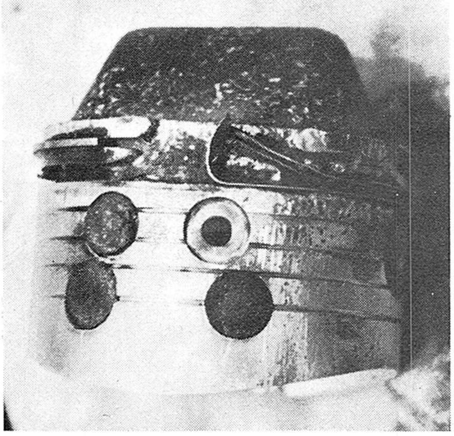
TWO-STROKE CYCLE

This drawing from a Hodaka manual gives you the idea of primary compression on a two-stroke along with the two-stroke cycle. At left, piston is at the bottom, exhaust is happening, other things too. Don't worry about them right now. At right, piston has moved up creating partial vacuum in crankcase. Fuel-air mixture from carb rushes happily into crank. Then piston starts down again, closing off inlet port. Mixture in crankcase begins to suffer from primary compression due to downward movement of piston. Crafty piston uses its top side to open up transfer port leading from crankcase up to combustion space in cylinder. You can barely see lower transfer opening behind con rod in right-hand drawing, top of transfer port in left-hand drawing.
Soon as top of piston opens transfer port, mixture being squeezed in case rushes happily up topside. When piston gets to bottom of its stroke, it has urged as much mixture as possible to leave the crankcase and go upstairs. Then piston moves up and closes off the transfer port. Then it closes off the exhaust port as it moves farther up. Mixture is trapped. Piston moves on up as shown in drawing at right, compressing mixture again and just before TDC spark plug sets it on fire.
Mixture finds this unendurable, pushes piston down to open up exhaust port and gets out of there. However downward movement of piston is simultaneously compressing next batch of mixture in crankcase, opening transfer port, and new charge flowing up through transfer ports is helping to push out the residue from previous combustion. Called scavenging. Whole business is incredibly complicated, isn't it?



The Wild World Of Drag Racing

Here's a piston that Dave doesn't need anymore. Probably pre-ignition. Maybe just the intense heat of supertuning. Teflon(TM) buttons reduce friction in the bore.



Drag racing probably represents performance tuning raised to the highest level.

These engines do amazing things for ten seconds or less.

Run one twelve seconds and you may take it home in a basket.

If you count the top professional motorcycle drag racers on the fingers on one hand, Dave Campos of Albuquerque will be among them. Dave manages, most of the time, to tune in that narrow band between maximum performance and melted pistons.

Here's how he deals with some of the tuning variables:

Air density provides the critical information needed to tune on the ragged edge. At 5,000 feet altitude, on a typical summer day, here are the settings for Dave's fuel dragster:

Air Density	–	about 80%
Main Jet	–	235
Idle Jet	–	70
Ignition	–	45° to 48°

At drag strips in the Los Angeles area, the settings change to something like this:

Air Density	–	about 100%
Main Jet	–	271 to 275
Idle Jet	–	80
Ignition	–	45° to 50°

With these settings, Dave runs over 160 miles per hour. So, he ain't just foolin' around.

During preliminary set-up runs, Dave advances ignition until one of three things happens:

Dave Campos, above. At right, Joan Campos: housewife, business manager, schedules Dave's appearances and tours. Raises the kids. Also drives the truck. Knows more about motorcycles than most guys. Passenger is Phil York. Helps Dave tweak the drag bike. Rides fast once in a while himself. Phil holds three Bonneville records. When he talks about fuels, it's a chemistry lesson.

- Detonation—When he hears the beginning of detonation, he retards spark until he doesn't hear it any more.
- Slower Time—On some days, he can advance timing until some setting gives him a slower speed. He retards back to the timing which gave the best performance.
- It Runs Fast Enough—If the machine performs as well as he thinks it should, and well enough to give him a chance to win, he quits advancing spark. Trying for just a little more may blow the engine.

At West Coast sea level, Dave starts with the 275 main jet when air density is near 100. Sometimes dropping to a 271 will improve performance, which suggests that the 275 was a bit rich.

Example:

275—161 to 162 MPH
271—163 to 164 MPH

At those speeds, an increase of one MPH requires a lot more power. Why doesn't he try something like a 268 jet, when a 271 is better than a 275? Hard experience and melted pistons. Dave knows the limits.

Does air density make a difference? At RAD 100, when things are right, he gets 164 MPH. At RAD 102, he runs at 165. At RAD 105, he gets speeds of 168 MPH. Air density makes the difference.

The fuel used is nitromethane, blended with propylene-oxide and sometimes benzol. The temperature of the day affects the density of the fuel, so Dave carries a hydrometer (which measures specific gravity or density) and checks the fuel density before blending.

The main reason for this is to keep one of the many variables constant, or at least known and under control. It's simpler to make the fuel uniform to start with than it is to try to tune for fuel density variations, along with all the other variations.

During a day, the fuel blend will be changed as the air density changes, because it is easier and quicker than changing jets.

Nitro is an oxygen-bearing fuel, containing about 50% oxygen. The additional oxygen for combustion comes from the air, which holds about 20% oxygen.

Since the oxygen content of fuel and air is about a two-to-one ratio, Dave has found that a 1% decrease in air density can be compensated by about one-half percent increase in the density of the fuel. When air density goes up, fuel density is lowered by adding more propylene-oxide or benzol, and the reverse.

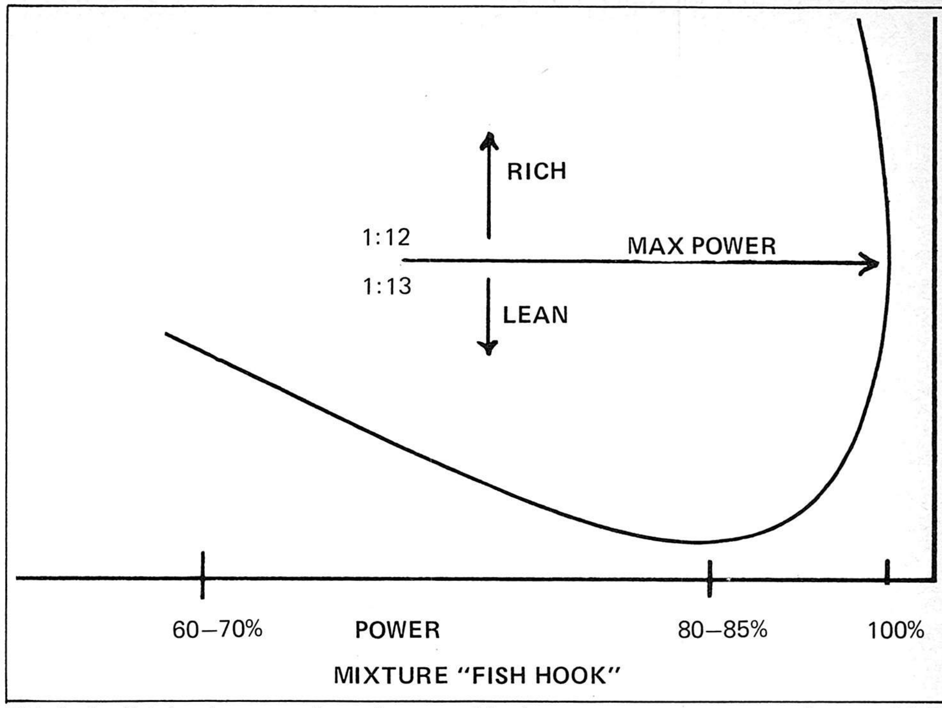
Like championship chess, championship drag racing is really an intellectual sport.

The guy you see putting on the big show, with much smoke, noise, and outrageous speed, is probably listening to his engine while racking up the tuning variables in his head, and he is already figuring what he is going to change so he can go better.

The show is over in less than ten seconds. But, to the drag racer, the show is the least part.

The tuning is the challenge.

The Importance Of The Variables



This is the fish hook arranged another way. Maximum power occurs at a mixture which is neither rich nor lean if you are after maximum power—it will be around 1:12 or 1:13 but you don't find the max power mixture by measuring fuel-air ratio, you find it by measuring power. When you are "cooling it" and using only 80 or 85 percent of max power, the carburetor should be furnishing a mixture which is lean compared to the max-power mixture. This is the maximum-economy way to operate your engine.

Rider ability counts a lot in extracting performance from a bike. Some say that it is 80% rider and 20% motorcycle. It may be the other way around.

Good riders are seldom on poor bikes. They are sensitive to performance—more than the average rider—and they are usually good tuners or have a skilled tuner preparing their machines.

Suppose, in a race, the lead rider has a bike which delivers 5% more power. He will appear to be running much faster than the second-place rider. However, if you time them with a stopwatch, he may be running only 5% faster (which always looks like a much higher percentage). If so, then the lead rider's skill is simply to use the extra 5%.

The rider behind may have the same level of ability but be handicapped by reduced power.

Certainly, any rider will do better with a better-performing machine. It helps to know the potential payoff from the tuning variables, so first attention can be given to the areas with the most promise, followed by the search for smaller improvements if desired.

It is not possible, in most cases, to give exact payoff numbers or percentages because effects vary with engine design and the mutual interactions among the variables. The following discussion will convey the relative importance of the tuning variables along with an indication of the magnitudes.

F/A RATIO

If an engine is held at a fixed RPM, mixture and spark adjusted for maximum power, and then a curve is plotted of F/A ratio versus engine power while mixture is varied, a fishhook curve results. Spark timing may be noted on the chart, or taken with the data, and a separate plot of timing versus RPM can be obtained.

Engine builders take such data over the entire RPM range of the engine, in steps of 500 or 1,000 RPM. The resulting family of curves is then combined in several ways. One is to yield the published horsepower curve for the engine. Each data-point on such a curve results from a measurement of power, at that RPM, during which both mixture and ignition timing have been optimized.

The published power curve thus represents the best that can be obtained. To realize such performance from a particular engine would require an ignition-advance curve which exactly duplicates the engine requirements at all RPM values and a carburetor which provides exactly the right fuel-air mixture at all times.

The value, to the tuner, of a fishhook curve is that it shows how power varies with mixture and gives some idea of how much.

Approximate values for F/A ratio and power percentages are shown on the chart. The chart is generally representative of internal-combustion engines, however an engine can be considerably more or less sensitive to changes in F/A ratio, according to its design and state of tune.

The fishhook also illustrates, as pointed out earlier, that the sensitivity of power to mixture is less, on the rich side.

When making carburetor adjustments, it is useful to have a mental picture of the fishhook and make tests to determine where the engine is operating on that curve. For instance, if a higher F/A ratio (a larger jet) causes an increase in power, it can be assumed that the operating point was on the lean side.

Where is the power?

Many tuners will say they are running a bit lean to get maximum power. When questioned about this, things become confusing.

"Lean from where?" you ask.

"Lean from where there isn't so much power."

That's true, and shown on the curve. If the mixture is a little too rich, and it is leaned down, power will increase. But that does not mean that there is more power because it is lean. It means there is more power because the mixture is better.

Next question. "How do you know you are lean?"

"The plugs show it."

If a rider finds best performance with a plug which doesn't color much, he may be using a plug which is slightly hot for conditions inside the engine. This is entirely acceptable as long as the hot plug does not cause other problems, such as preignition.

Suppose, in the case above, a still hotter plug is substituted in the engine and the plug burns up. Obviously, this is not evidence of still further leanness.

Also, plugs differ. Same heat range out of same box may "color" or "read" differently and may even be of different *actual* heat range.

When people say—"the way to get power is to run leaner than the degree of richness which gives you not so much power,"
Don't worry.
Power is where you find it.

MIXTURE COOLING

Since richer mixtures tend to cool more, and lean mixtures tend to cause excess heating, the F/A ratio is manifested both by the power developed and the condition of the spark plug.

If the spark plug in use has the heat rating recommended by the manufacturer, and everything else is right, one judgement can be made with near certainty from looking at the plug. If the plug looks right, the temperature in the engine is OK.

The mixture which causes the plug to look right is probably within one or two jet-sizes of the mixture which produces best power.

Consequently, some tuners adjust mixture until the plug looks right and then assume that mixture is also correct for power.

It is better to read the plug for temperature indication, and test separately for engine power.

At a drag race, the engine may be operated at full throttle for ten or fifteen seconds and then shut down. This results in maximum heat being "thrown at" the plug over a very short period of time. Since heat-flow away from the plug takes time, the early temperature of the plug will be higher than it may be later on when heat starts flowing away from the plug at some steady rate. The hot appearance of a plug after a drag race does not necessarily mean that the mixture is lean or that the plug is too hot for other uses of the engine. It simply means that not enough time was allowed for conditions to stabilize.

A similar thing can happen when tuning an engine on a dynamometer. For example, the engine can be put under load at high RPM and the ignition timing varied for maximum power. The power reading taken is very brief (called flash reading), and the heat buildup in the metal parts of the engine may not reach the high value that it would reach given longer time at that load and ignition setting.

The result can be that when the engine is taken off the dyno and run under normal operating conditions it goes into detonation.

Section ten is an account of tuning a bike by making performance measurements and optimizing jetting and timing. The performance measurements were made during very short runs at full and half-throttle settings. Between tests, adjustments were made, allowing the engine to cool off some. A carburetor main jet was selected which seemed to give maximum power.

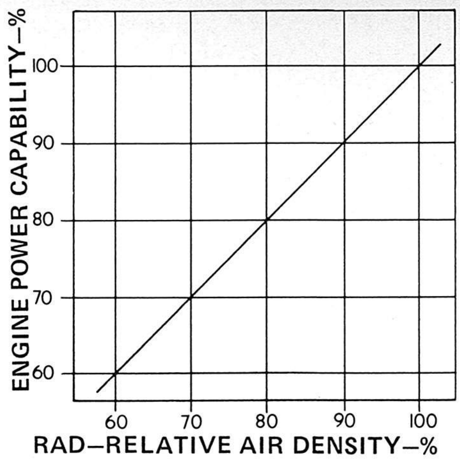
In later road-testing, when the bike was subjected to long pulls on a slight upgrade, the full-throttle mixture appeared to be slightly rich, because mixture burns better and vaporizes more at higher temperatures. The main jet was reduced in size by one step with no observable decrease in performance.

All of the above are indications of temperature changes with mixture and indications that stable conditions should be achieved before drawing conclusions.

The importance of the cooling effect of mixture as a tuning variable is that it can be used, sometimes, to correct other problems. If an engine is getting too hot, one expedient is simply to dump in more fuel, hoping that this will cool it off.

AIR DENSITY

Air density affects engine performance in several ways. It affects metering in the carburetor, as discussed. It affects the oxygen content of a given volume of air and therefore the power capability of an engine. It also affects the pressure in the cylinder and therefore the ignition-timing requirement.



If Relative Air Density goes up, which you can check with an air density meter or the RAD chart on the inside back cover of this book, then the engine power *capability* also goes up by the same percentage. You won't automatically get that increased power unless you tune for the changed air density.

POWER CAPABILITY

Assuming carburetion and ignition are both set for changes in air density, then the dominant effect of a density change will be a change in the power output of which an engine is capable.

The change in power capability is in direct ratio to the change in density. If density changes, up or down, by some percent, then power capability will change by the same percent, in the same direction.

TIMING

A typical curve of power versus spark advance shows about 20% decrease in power resulting from a change in spark advance of about 50% of the optimum setting. Some engines will change much more than this.

Since the curve rounds off at the top, the sensitivity of power to timing is less when the timing is close to optimum than it is when the timing is way off.

When a bike with mechanical points is ridden, the spark is gradually retarded due to wear. If ridden until performance is noticeably bad and the timing is checked, it will be off by

about a half-inch as measured on the circumference of the flywheel.

Typical flywheel diameters are about six inches, so this represents a timing change of about ten degrees retarded. If the correct timing is around 30 degrees, this represents a change of about 30%. This will produce a power loss of around ten percent, which is the amount that an average rider will notice.

A lot of practical tuners of high-performance engines will argue with a curve which shows power declining in both directions from some optimum ignition setting, because it is contrary to their experience.

These tuners have found that timing should be advanced until detonation just begins, and then retarded slightly. As discussed in section four, this is the case with a detonation-limited engine.

LOST COMPRESSION

The theoretical expression for thermal efficiency is:

$$e = 1 - \frac{1}{R^{(n-1)}}$$

where e is efficiency, R is the compression ratio, and n is about 1.3 for a mixture of air, fuel, and exhaust products.

As a guide to the effect of lost compression, the equation above has been plotted as *relative power* (in percent) against actual compression. The curve is on the following page. The 100% point on the curve is arbitrarily chosen to be at a CR of 12:1.

This curve shows the change due to compression gained or lost and also shows that the incremental benefit is less at higher ratios.

In the region of usual CR values, a drop from 7 to 5 CR causes a reduction in power of about 10%, or about 5% per unit of CR. This is less at higher compression ratios, as the curve indicates.

Compression pressure is normally checked with a gage while cranking the engine with throttle open and switch off. If we assume that this low RPM allows enough time for the air in the engine to reach atmospheric pressure at the time the inlet closes, then the compression gage should read something near atmospheric pressure multiplied by the compression ratio. The gage will actually read higher than this, for reasons discussed separately.

However, if we make the simplifying assumption that a drop of 15 psi in the reading of the compression gage represents a loss of one unit of CR, we can arrive at a rule of thumb.

For moderate compression ratios, a decrease of one atmosphere in gage reading will decrease engine power output by about 5%.

Honda shop manuals supply tables of compression values for various models. The tables give normal measured compression values, a lower value at which repair is indicated, and a higher value at which repair is indicated.

These values, typically, allow about two atmospheres (30 psi) drop in measured compression before new rings, a rebore, or a valve job is indicated. This "tolerable" loss of power is about 10%, before recommended overhaul.

Since we have concluded that a 10% power change should be noticed by the average rider, it appears that the recommendations call for overhaul just about the time the rider begins to think something is wrong.

The higher compression limits, incidentally, mean that carbon buildup has raised the CR to the point where detonation may occur.

At higher altitudes, normal readings will be lowered in proportion to the lower air density.

The important thing, in monitoring engine compression is not the compression readings, but the reduction from readings taken when the machine is in good repair, or when the machine is new. Another important reason to keep records.

SOME HONDA COMPRESSION PRESSURES

Disp.	Normal	Low	High
70	170	128	200
90	171	142	200
175	142	114	172
450	185	164	213

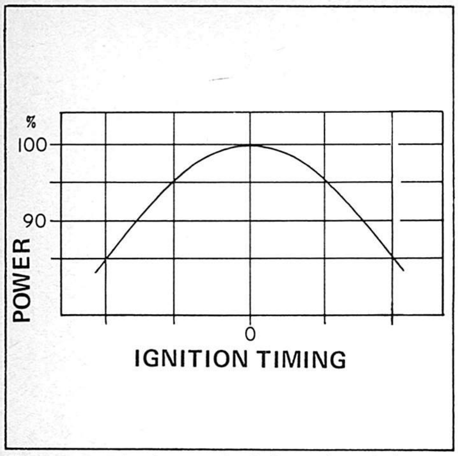
Sad Joe—bought a bike and rode it a long time around Houston. Nobody told him it needed maintenance.

Then he moved to Denver. Nobody told him about air density and tuning.

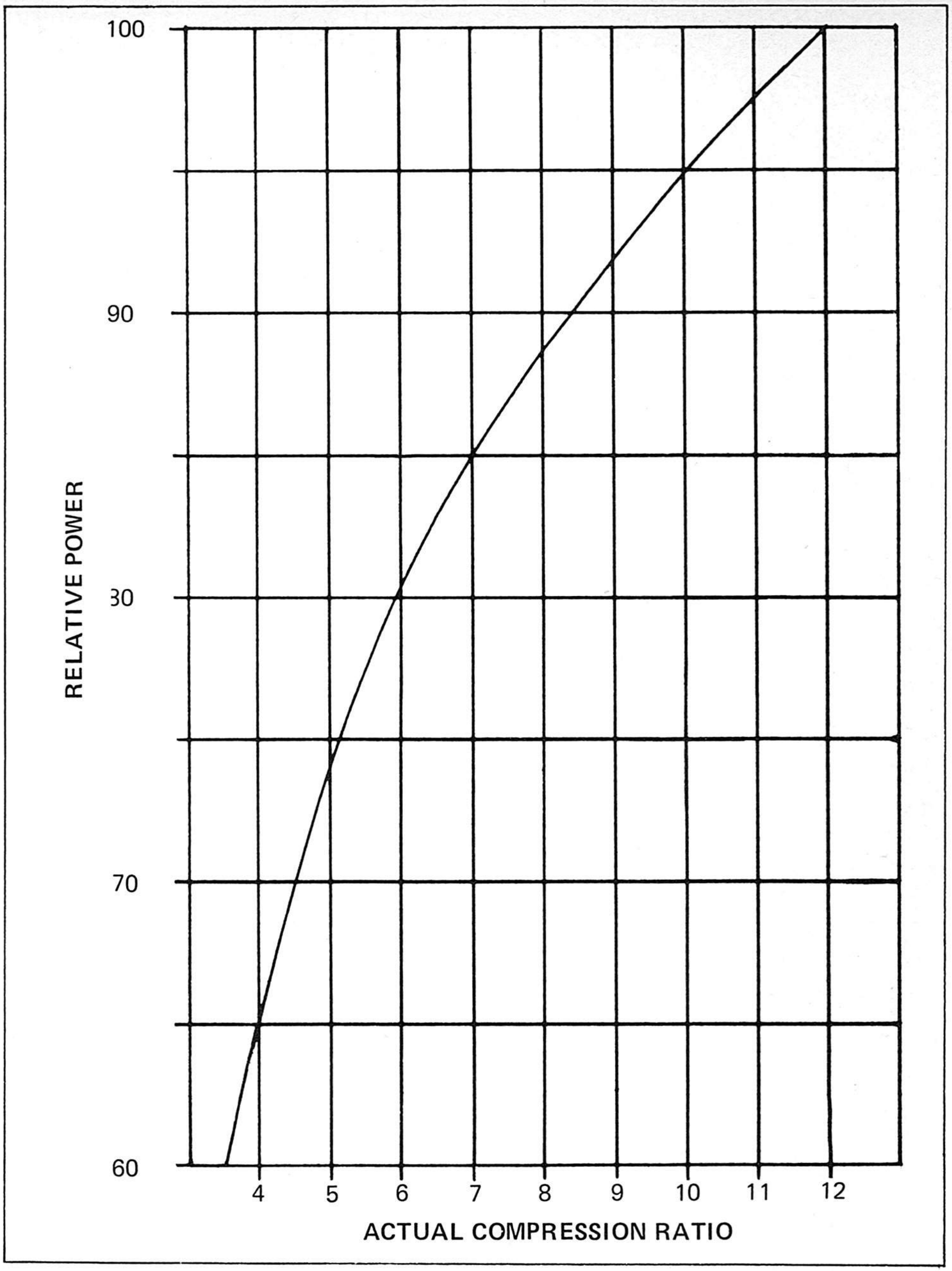
His bike didn't run well!

Timing off due to ignition wear	10% less power
Compression loss due to ring wear	10% less power
Reduced air density	20% less power capability
Uncorrected F/A ratio	4% below capability
Uncorrected ignition timing	2% below capability
Percent sadness:	46%

Of which Joe can get back *more than half* by maintenance and tuning.



This curve is theoretical, based on lab measurements of typical engines both two- and four-stroke. It shows you get best power when the ignition timing is spot-on. Go either way and power is reduced. Other bad things happen too, such as increased heating, poor economy, detonation and pre-ignition. If you have to miss, it's safer to have ignition retarded, rather than advanced too much.



Another theoretical curve. I solved the horrifying equation in the discussion of lost compression, diddled the data to show 100 percent power at an arbitrarily-chosen compression ratio of 12. It shows among other things that the benefit of increased compression is less if the engine is already running high compression. Notice how much more power you get by increasing compression from 6 to 7, compared to an increase from 10 to 11.

A trials-bike engine usually has low compression, mild port timing and reduced ignition advance to favor low-speed chug power. This good H. P. Book, HOW TO RIDE OBSERVED TRIALS tells you how to have fun with such an engine.

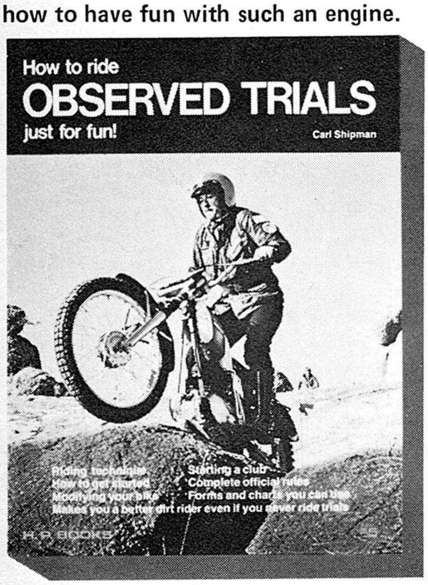


Photo courtesy PATRACO.

Measurement Of The Variables

This section discusses methods of measurement of each of the variables. The object is to find something to check or look at that will relate to a single variable, rather than one or more in combination. Sometimes we can, sometimes we can't, but we can always come reasonably close.

The main variable, of course, is power—the starting and ending point of each adjustment.

DYNO

The handiest way to tune is on a dyno. The main precaution is to remember that the settings chosen may result from short bursts of power and therefore may not be suitable for normal use.

A dynamometer is a brake, and they are sometimes called that. Their function is to apply a mechanical load to an engine which absorbs the power output of the engine.

The device can look exactly like a brake, and the

earliest versions were just that. Friction was applied to a rotating shaft or drum which was driven by the engine under test. When the amount of friction was such that the engine speed neither increased nor decreased, then the power output of the engine was being exactly dissipated by the heating of the brake, and could be exactly measured.

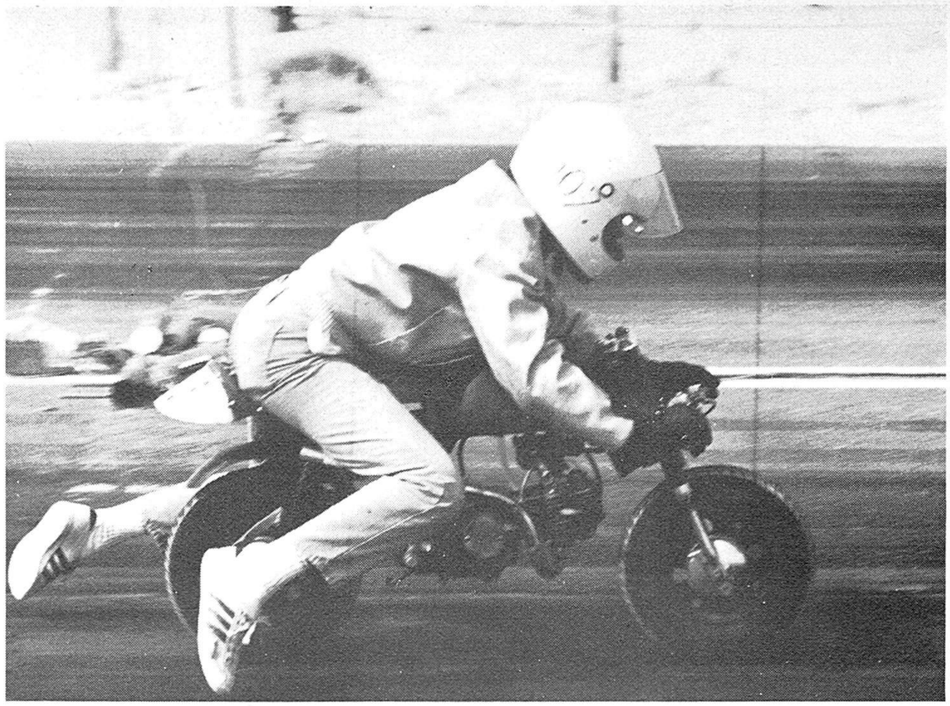
If you imagine that you are applying friction to the motor-driven shaft with a couple of friction pads which you hold in your hands, then you, as a dyno, would sense two things. The pads get hot, and they have to be held with a force opposite to the direction of shaft rotation so that they (or you!) don't rotate with the shaft. The force applied to keep the pads from rotating is a measure of the torque output of the engine.

Either of the above may be used to determine the power of the engine—the heat or the force. It is usual to get rid of the heat by a cooling system and measure the force required to keep the brake from rotating with the engine.

If the force is measured at some known radius, the measuring instrument (such as a spring scale) can be calibrated in units of torque, or torque can be calculated from the data. If RPM is also measured, by a second instrument, then the product of torque and RPM is horsepower which can also be calculated, read off a chart, or read directly from the dyno control panel.

For any throttle setting, power is a function of RPM. Therefore the load can be varied until some desired RPM results, and the power or torque reading is then valid for that RPM.

Modern dynamometers rarely use friction pads to absorb engine power on account of rapid wear and the problem of getting rid of the heat. They use electric or hydraulic means to absorb power from the engine under test.



Phil York dragging with his Bonneville-record-setting Honda. Phil also rides big bikes on the salt but this is the machine folks in Wendover, Utah remember. When he checks into a motel people whisper, "There's that kid with the fast minibike!" Photo taken by Bob Thanisch through the fence, as you can see.
As mentioned in the text, the drags are a good place to tune and test provided you can get in a lot of runs and *provided* you remember that carb and ignition settings for a quick charge down the strip will not be right for long continuous full-throttle operation.

THE DRAGS

The drags are a fine place to tune because the measurements are handy, quick, and accurate. The same precaution applies—the time that the engine is under load is usually brief.

Drag strips measure ET (elapsed time) over a quarter-mile distance, and also the speed of the vehicle at the end of the run. Speed is obtained by measuring the time required to pass between two closely-spaced markers at the end of the strip. The time interval is converted into MPH automatically by the timing system.

When drag-strip data is used for tuning, the tuner has the choice of using ET, speed, or both as the power indication. Considering that moving the vehicle from one end to the other represents work done in overcoming air resistance and rolling resistance, and remembering that power is work divided by time, we can conclude that a lower ET indicates higher power.

Most vehicles are no longer accelerating at the end of the strip and have achieved maximum speed. When this is the case, RPM is stable and all of the power from the engine is being used in overcoming resistance to forward motion. Therefore higher speeds also indicate more power.

At speeds above about 50 miles an hour, air resistance is the dominant factor. Air resistance is non-linear and increases at the square of the speed. Therefore neither ET nor maximum speed have a linear relationship with power.

In other words, to get a 5% increase in speed, or a 5% decrease in ET, will require considerably more than a 5% increase in power. However, the tuner is mainly interested in finding the settings which give maximum power and does not really need to know the actual amount of power being developed. Consequently, either ET or speed can be used as an indicator.

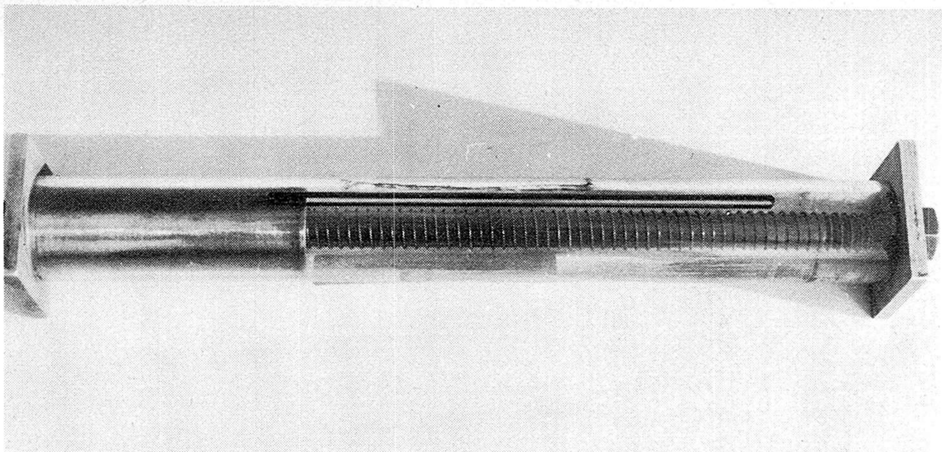
Top speed is a more direct indication of tuning and a more reliable indicator. Anything which increases top speed is a sign of improved tuning or adjustment.

ACCELEROMETER

Anybody who paid attention to basic ideas of mechanics (physics) came away with a simple equation lodged in memory.

$$F = ma$$

where F is force, m is the mass of an object, and a is the acceleration due to the



Simple-minded accelerometer I built to see if it would work. Brass weight slides along rod, compressing spring as it goes. All enclosed by clear plastic tube with scale taped on opposite side. Slot in this side was to allow weight to move a pointer if desired. Thing worked well enough to vindicate science, but I decided stopwatch or dyno is handier.

applied force. For a vehicle with some particular mass or weight, acceleration is directly proportional to the applied force.

Since the engine makes torque, basically, and since torque is force, then acceleration is proportional to torque. If a bike is being operated at part throttle, and the throttle is then fully opened, the acceleration will be determined by the amount of torque in excess of the amount which was being used at the steady speed.

It is logical to measure the peak torque, in some gear. Since this does not require use of top gear and does not require running at top speed, the use of an accelerometer offers some advantages to the tuner. Performance can be measured at legal road speeds on any level surface, and without a measured course.

Nothing simple enough to be used on a bike could be found, so we built one—a triumph of simplicity—based on that great truth, F = ma.

A one-pound brass weight was machined with a hole down the center, so it could travel along a polished rod. The weight compresses a spring with a spring constant of 0.2 pounds per inch. This means that a force of 0.2 pounds will compress the spring one inch.

When being accelerated at one g—the acceleration of a free-falling body due to gravity—a one-pound weight will exert a force of one pound. The weight in our accelerometer will compress the spring five inches, so the scale of the instrument is five inches long between zero and an acceleration of one g.

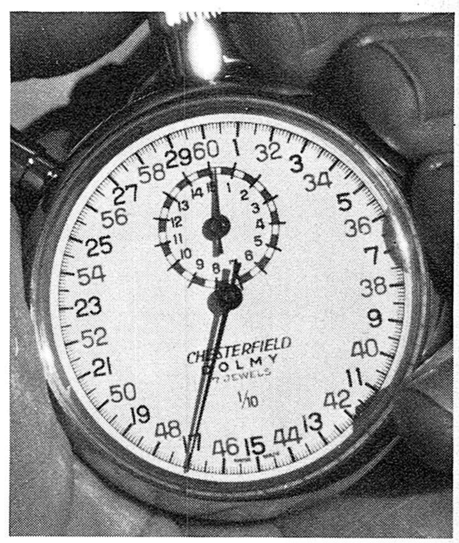
The spring was preloaded (initially compressed) so that the scale actually read from 0.3 g to 1.3 g.

This proved to be an entirely satisfactory tuning indicator. When strapped to the tank, on a foam pad, and pointed in the right direction, the weight moves in accordance with the torque curve of the engine. When reversed, the accelerometer tests the brakes.

Our final conclusion was to return to tuning with a stopwatch, as described below. We have a handy place to tune, where we can run at top speed without bothering anybody or attracting volunteers in neat uniforms who also wish to measure our speeds.

So, the bike accelerometer occupies a place of honor in the burial ground of our other great ideas which include several other designs for accelerometers, a non-linear throttle mechanism, and a contraption to change the tuning of a resonant exhaust in accordance with engine RPM.

It isn't a bad idea. They are easy to build. And, we may return to using it someday.



STOPWATCH

Among the methods of performance measurement which are readily available to anyone, the stopwatch is probably the easiest and best. By setting up two markers, running between them, and timing the interval, an indication of speed or power is obtained.

This is equivalent to having your own drag strip and equally annoying to close neighbors.

The run must be started far enough back so top speed is achieved before entering the measuring section. Some bikes are geared so that they can exceed the RPM limit of the engine in top gear on a level road. Since this shortens engine life and can cause sudden destruction, running this way is not desirable.

If the course chosen is uphill, then the performance measurement retains its significance, but the engine RPM is not as high.


Where we tune. No traffic. No Neighbors. Slightly uphill.

Greater precision of time measurement results when the markers are far apart. The stopwatch should read to 1/5 or 1/10-second.

If readings are taken to 1/10-second, and the time interval being measured is about three seconds, then a tenth of a second represents a change of about 3%. Course markers which allow three-second running time intervals are about as close together as can be used and still derive any benefit from the measurements.

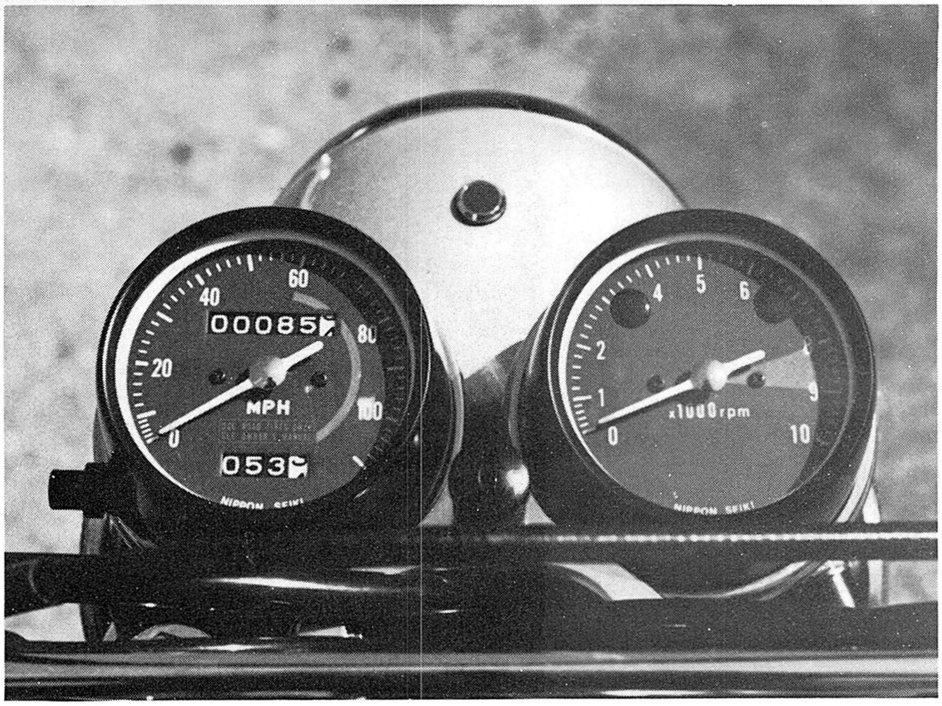
Most bikes will over-rev easily in the lower gears, so it is desirable to make the runs in top gear, or at least a higher gear. Running uphill helps this situation and also increases safety by allowing lesser top speeds.

Readings should be taken both at full-throttle and at half-throttle or 2/3-throttle, in order to get data pertinent both to main-jet size and needle setting.

Readings should be an average of several passes. With a little practice, the readings will be very consistent among several runs under the same conditions.

Since air density variations will affect performance, the RAD (Relative Air Density) should be known and recorded with the test data, as discussed later in this section. Barometric pressure is not likely to change very much over a period of a few hours unless the weather is visibly changing. Temperature will change during a test period. Each change in temperature of five degrees Fahrenheit will change power capability by about one percent. A temperature change of 10 or 15 degrees, while measuring and tuning, can cause effects about as great as the fine tuning changes, and can make the whole procedure meaningless. When the temperature changes this amount it may be a good idea to suspend testing until the temperature returns to the value you are using, with another check on barometric pressure—or another reading of RAD.

With a little practice, careful testing and tuning, along with records of the data, the results



Many riders keep check on performance by noting speedo or tach reading at some location where they ride regularly. Start at the same place each time and speed or RPM at the top of your favorite hill is a good indicator of engine tune.

of using this method can be very surprising.

Please don't harm the sport by tuning this way in populated areas.

INSTRUMENTS

If a motorcycle has a speedometer or tachometer, either can be used for testing, using the same general procedure as above. Markers are not required for timing, however the bike instruments should be read at the same place on some uphill section, so some kind of a marker promotes uniformity. When top speed is achieved, either the reading of the tach or the speedo is an indication of power.

These instruments are probably not accurate within five or ten percent, however absolute accuracy is of little concern. They will show changes in successive tests, which is all the tuner needs.

The main problem is difficulty in taking readings due to vibration, wavering needles, and the scale calibration intervals. A stopwatch, used over a fairly long measuring interval, will do a better job of finding small performance improvements.

F/A RATIO

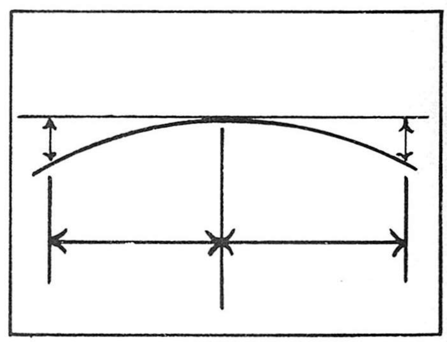
The most precise method of measuring F/A ratio is by use of a combustion analyzer, which detects the presence of unburned hydrocarbons in the exhaust.

The principle depends on the fact that unburned fuel in an exhaust gas will affect the temperature of a heated wire which is immersed in the exhaust stream. This temperature change due to the exhaust products is sensed electrically and displayed on a meter.

These instruments are more suitable for use on engines in a dynamometer room, however they can be attached to a bike and rider and the F/A ratio can be measured while the machine is traveling.

POWER AS AN INDICATOR

There are simpler but less precise methods than use of an exhaust analyzer. The power developed is an indication of F/A ratio. On some engines, the power change is small when the mixture is near optimum, and these changes may be hard to detect.



One method which is useful in finding the peak of a nearly flat curve is to make increasingly large excursions in each direction from the peak, until some plainly detectable result is observed. Then, the peak can be estimated by saying, perhaps, that it is halfway between the two places where change was perceived.

A Night On Dave's Dyno

In the first edition of this book, I treated dynos as a rarity, unavailable to the average rider. There is now a definite trend among motorcycle dealers, large and small, to install dynos and therefore they are not so rare anymore. It is likely that you will be able to get your machine on a dyno soon, if not right now, at some nearby shop. To give you a feel for what it is like—or what it can be like—here is an account of an evening I spent recently with some bikes and a dynamometer.

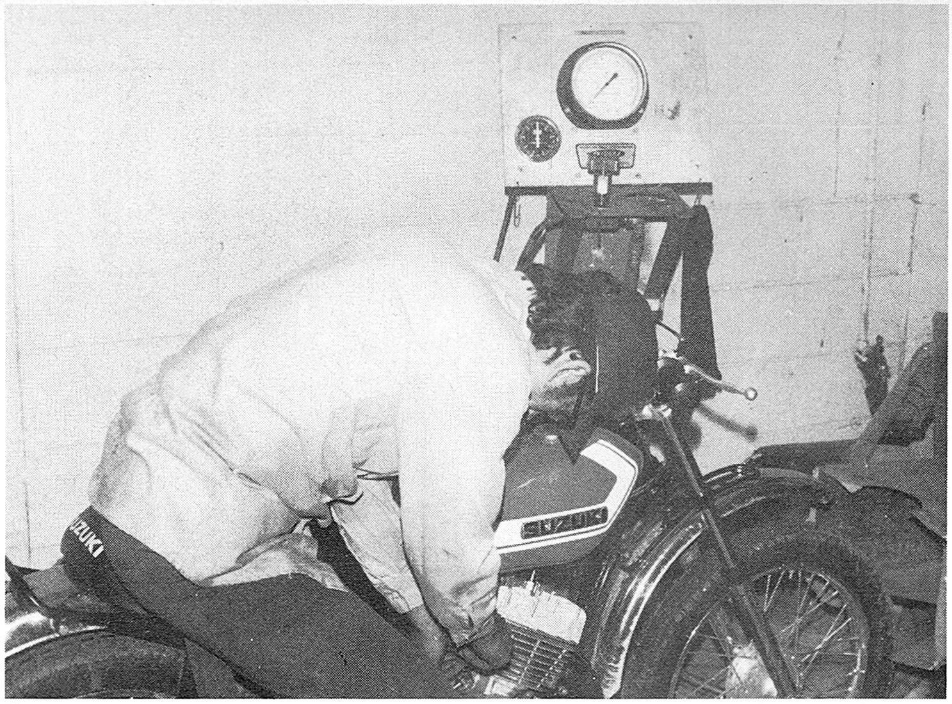
At Motorsport, Albuquerque dealer for Suzuki, BMW, and Triumph, serious riders have the next best thing to owning a dyno. They have access to the shop dyno after hours, every Thursday night.

This dealership is run by the Bodwell family, the shop by Dave Bodwell, and it's Dave who stays late on Thursdays to help guys sort out their problems. You don't have to be a customer and you don't have to ride one of their brands. Bring anything, along with your own tools and spares, and have at it.

There is a modest charge for time on the dyno. Everything else is free: Dave's advice and recommendations based on his use of the machine as normal shop procedure over the past five years. Advice and help from the half-dozen or more riders and mechanics who are there on Thursday nights. An education, just from watching the things that happen. Plus gentle humor, sometimes crudely put, and the comradeship of these free spirits with greasy hands. Sometimes it gets so friendly or interesting technically that even the dyno time is free.

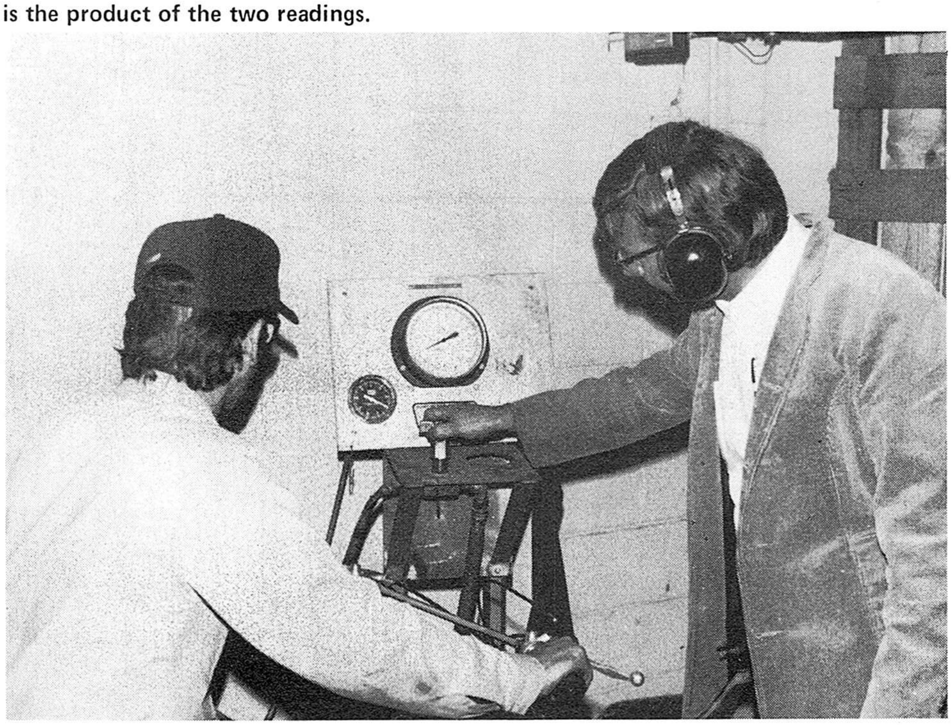
On a rainy Thursday night, three bikes were put on the "pump." Larry Kneblick's 185 Suzuki was run briefly to verify carb settings. Doyle Fincher's 250 Suzy MXer had developed a high-speed miss and was scheduled for diagnosis. This led to a very interesting result which can affect nearly any bike and which will be described as we go along.

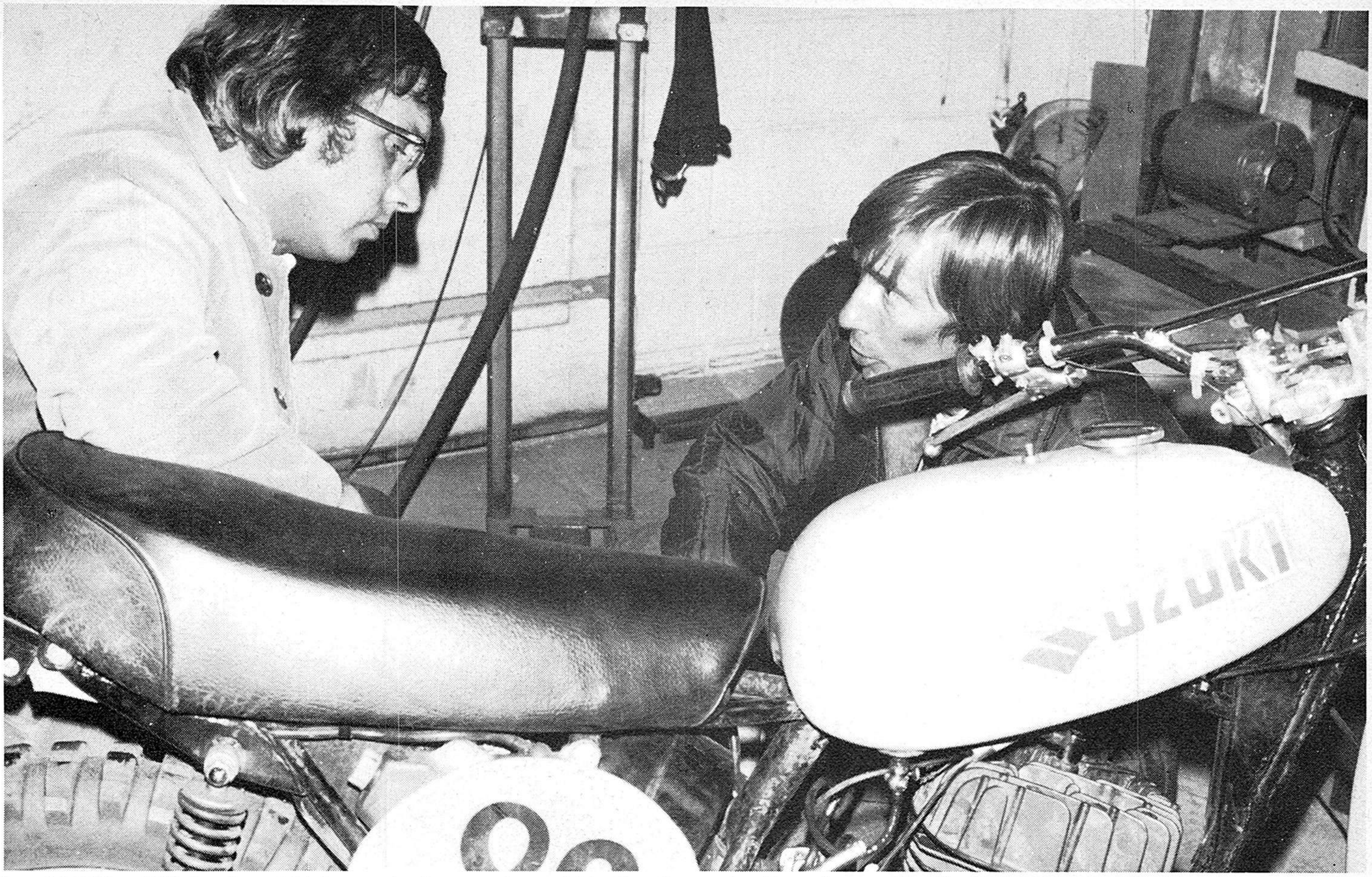
The third machine was Mike Murphy's venerable and much-modified 250 flat-tracker. When a bike gets this far out, it defies any logical process of the mind. You assemble it by testing, taking



Gene Tally changing jet on Suzuki 185 with hop-up kit. This dyno run was to check jettings.

Gene runs up bike while Dave Bodwell operates control valve to put load on engine. Large dial reads hydraulic pressure from dyno, small dial reads RPM. Horsepower is the product of the two readings.





Suzuki 250cc MX developed high-speed miss, was brought in for diagnosis. Dave listens skeptically while owner Doyle Fincher says, "Honest, I didn't change nothin!"

the pragmatic view that "What works, works." The intent was to test two different barrels, one highly ported by Gene Tally, carbs of two sizes, two different pipes, jets, and ignition timing.

After the 185 had been jetted, the 250 motocrosser was put on the rollers.

Since this bike had been on the dyno before, Bodwell knew what to expect when it was run up. It did miss at high speed and power was off nearly 25%.

Shutting down, Dave said to Doyle, "What did you do?"

"Nothing. It's just like it was before."

They looked at the plug. It showed rich.

"How's your air cleaner?"

"Clean. I washed it out before I rode today, and didn't ride it very long on account of the miss."

In about a minute, the carb was in pieces. The primary choke was unaccountably dinged a bit, but not enough to cause the problem. It was straightened out with pliers. Everything else checked.

After a little more testing, Dave said, "There's gotta be something wrong with that air cleaner. Pull off the hose."

With the air cleaner disconnected from the carburetor, the machine wound and wailed. Power was there.

"Let's see the foam unit."

Like fifty-thousand other riders, Doyle had scrapped the stock foam air-cleaner and substituted an accessory foam unit. I have done it. You may have done it. It's something you do. Doyle did it. Bad news.

The foam looked fine. It was clean and properly oiled.

Doyle said, "I had this cleaner on the bike the last time we checked it out, and it had power."

"OK. Let's try a new one just like it."

Drawing a new accessory filter from stock, the machine was checked again. It was considerably better. Something had happened to the pores in the foam of the old cleaner. It looked OK, it was properly serviced, but it wouldn't flow air.

You can fiddle for six months with a problem like this. On the dyno, the problem was identified in less than an hour, with about three test runs. An impressive use of the dyno, as a diagnostic tool in the hands of an experienced tuner.

Doyle started taking his bike off the rollers.

"Hold one," Dave said, "now let's try the stock Suzuki foam unit." The way he said it, everybody knew he was gonna be right. They jerked one off a nearby demo bike and installed it. Power went way up.

Here's the comparison between the stock foam filter and the accessory foam filter. The accessory unit had about 30% more filtering area than the stock unit. The stock unit flowed better and gave significantly more top-end power than the brand-new acces-

sory unit.

This is not to say that accessory units are bad. Lots of people get improved performance and improved filtration from them. However, the factory units are also not necessarily bad, as people sometimes automatically assume. The factories have dynos too.

The main point is that you can get into trouble in unexpected ways. The high-speed miss was not due to improper carburetion and it was not due to ignition. It was simply a mysteriously deteriorated foam filter. The only way to find this kind of trouble is by cool, logical testing.

No horsepower figures have been given, even though the dyno provides them very conveniently, for a couple of reasons. First, on a chassis dyno, all bikes produce power below advertised claims. Advertised power, even if it's honest, is power at the engine, not at the rear wheel.

Second, and more important, on a chassis dyno, the power reading depends very considerably on the type of tire on the rear wheel and the tire pressure. Standard procedure, at Motorsport, is to inflate to 45 pounds before running on the rollers. This eliminates variation due to pressure, but does not take care of variations due to type of tread and type of rubber in the tread.

Some rubber has high internal friction (mechanical hysteresis) causing the tires to become very hot on the rollers, even tacky. This type of rubber, sometimes called cling rubber, is used in some tires because it literally makes the tread less "bouncy" and therefore the tire clings better. However, the power loss in heating up the tire is considerable and can make dyno readings meaningless, except to the operator who knows what to expect from different brands and types of tires.

Even though Dave's dyno will handle 90 horsepower and 120 MPH, he will not again put a 400cc motocrosser on the rollers with knobby tires. One time he did that, and the entire shop was deluged by a hailstorm of knobs.

The main uses of the dyno in this shop are to verify tuning of customer bikes, for diagnostic use, for tuning sessions on Thursday nights, and to play a chess game with an assortment of barrels, pipes, and carbs, in the far-out tuning regime.

In most cases, first test is a full-throttle maximum-load run to check the main jet size and plug. A half-throttle run is made for needle setting. Then, ignition timing is varied, sometimes requiring reruns for jetting again. When it's all done, the tuning is optimum for that bike, on that day.

On another day with different temperature, pressure, and possibly humidity, the settings will not be optimum on account of air density variations.

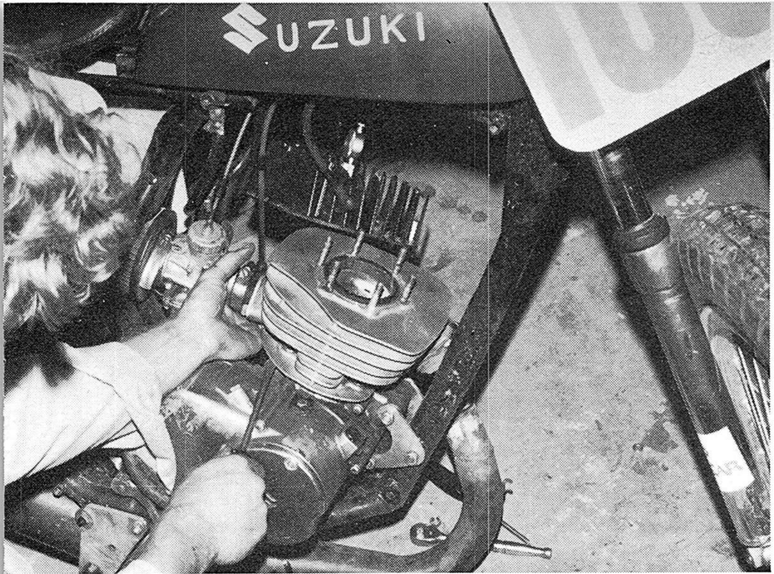
For serious riders, Dave will supply a chart showing jet changes for different altitudes. Complete correction would be for both altitude and temperature (Relative Air Density); however nobody can forecast the temperature, next month, someplace else. Jet corrections for different altitude will get some part of the job done and that is much better than doing nothing at all.

The dyno itself is nearly as simple as a stone. Much of it was fabricated by Bodwell and friends. It uses a centrifugal water pump, chain driven by the rollers, to absorb power from the bike. The bike, through the roller drive, operates the water pump. The load is regulated by a valve in the water line leading to the centrifugal pump. Give it more water to move and the bike has to work harder.

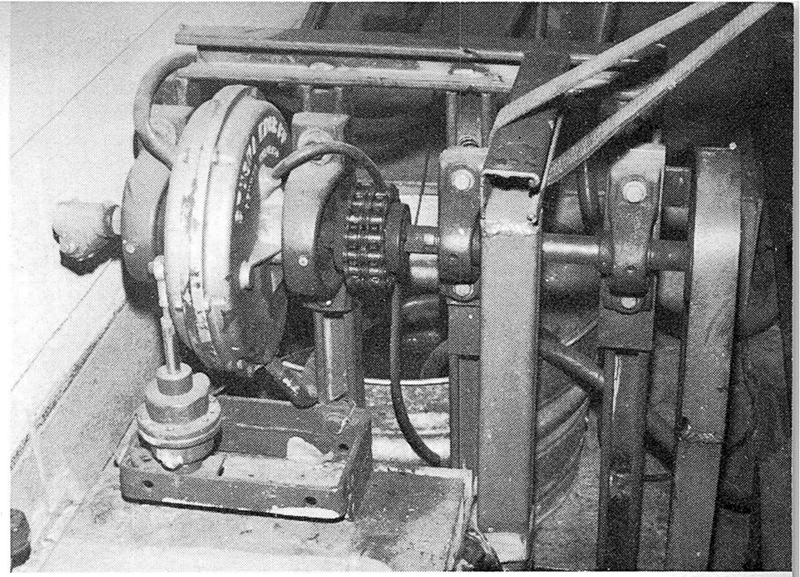
The outer housing of the pump is mounted in bearings, so it is free to rotate. If it were not restrained, it would go 'round and 'round with the impeller inside the pump, and it would not move any water through it. So, the outer casing is restrained by a hydraulic cylinder and the amount of restraint needed is a direct measure of the torque.

As the pump housing tries to rotate, it compresses the hydraulic piston and increases the pressure

Flat-tracker, with no kick-starter, had to be push-started in the rain. Owner, Mike Murphy, rides it onto the dyno rollers as John Shipman prepares to strap it down. Bike was newly set up and Mike wanted to see what it would do.



What it did was make that little tiny hole in the piston. New piston and another barrel were installed in minutes and testing resumed. Anyway, this is better than holing the piston at the track.



Power-absorbing element of this dyno is centrifugal water pump. Load control is by water valve in feed line. Pump shaft is chain-driven by rollers on test stand. Hydraulic cylinder on pump housing measures torque. Worm-drive on far end of pump shaft connects through cable to tach on control panel.

of the hydraulic fluid. A line from the hydraulic cylinder goes to the control panel, where the pressure is displayed on a gage.

Also on the panel is a tachometer, mechanically driven by the rotor shaft of the pump.

Horsepower, as you know, is torque multiplied by RPM. The two gages are calibrated so that horsepower is obtained simply by multiplying one gage reading by the other gage reading. The water valve, on the control panel, varies the load on the engine.

The engine runs as fast as it can, with a particular throttle setting and load. Thus, the torque-times-RPM tells the power being delivered into the dyno. As mentioned above, this is not the engine power output, or even power at the rear wheel when the bike is ridden on paving or dirt at normal tire pressure. However, for most practical tuning purposes, absolute power is not the important thing. Relative power or power changes supply the needed information.

With Doyle's problem solved, the group turned to the flat-tracker. In addition to the chess-game aspects of tuning that machine, there is even a problem getting it on the rollers because it doesn't have a kick starter. With a normal bike, a rider gets on it, starts it up while it is sitting on the rollers, shifts up through the gears, and testing is usually done in a higher gear. The bike is strapped down and none have ever gotten away. The unspoken rule is that if the bike suddenly desires to take a ride across the shop, the on-board rider is supposed to shut down.

Another unspoken rule of this game is, CHANGE ONLY ONE THING AT A TIME. This is routine for serious tuners. These fellows will talk about changing plug heat-rating, carb jets and ignition timing, all in one breath. But they will change only one of them at a time and see the result before changing anything else. Even if it takes longer, it's quicker!

The flat-tracker was push-started outside in the rain and then ridden onto the rollers. With the initial set-up, it went into pre-ignition almost instantly and melted a hole in the piston. Nobody thought much about it.

Murphy said quietly, "I'm glad I didn't haul it to the race at Amarillo this way."

Skilled hands put in a new piston in about as long as it takes to drink a cup of coffee. Because the first barrel had melted piston on it, they switched to the wildly-ported barrel to see what it would do and took a quick first check.

Through long experience, Dave Bodwell reads a plug for two things. Most of us read them for one. From the insulator, he determines how hot the plug has been, as we all do. From the metal, he reads mixture (aided by the dyno), and reads it *according to the type of oil* being used in the bike.

"You using Castrol, Mike?"

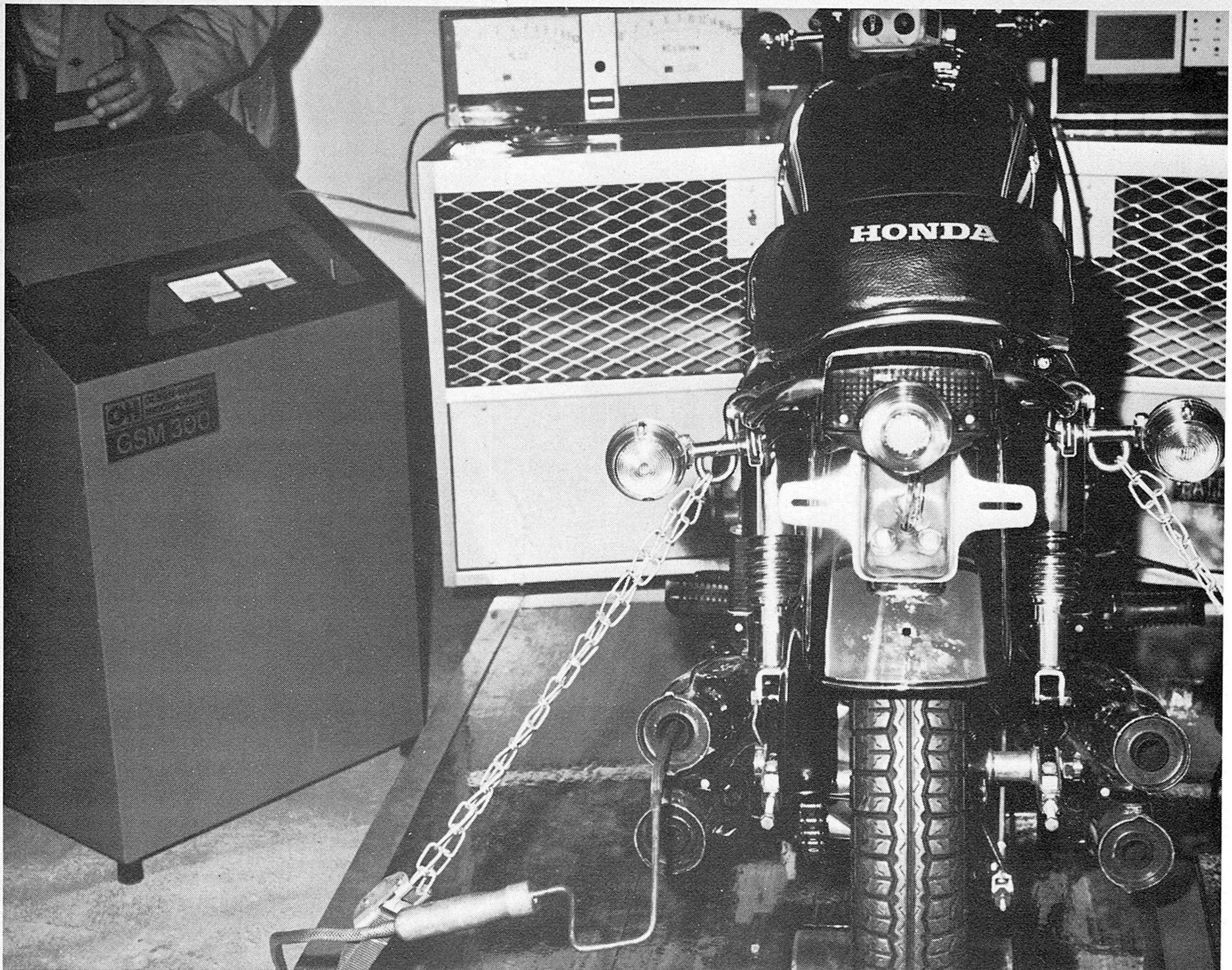
"Yes."

After examining the plug, Dave casually ordered a jump of thirty numbers in main jet size. When tuning a highly modified engine, in a configuration which has never been on the dyno before, one of the things you look for is some landmark to tell you where the tuning is.

Detonation and pre-ignition are such landmarks, speaking eloquently of such things as lean mixture, timing off, compression too high, wrong spark plug, or wrong fuel.

Another more desirable landmark is rich mixture, and richness never hurt an engine. One hundred jet numbers higher, they finally found richness! Maximum power was just below, but not enough.

While the rain walked across the roof and brushed against the big sliding doors, the pipes were changed on and off, ignition timing changed, and at ten-thirty the bike still was not right. Maybe it's the porting. One of the things to do is go back to the other barrel, when it's cleaned up, and repeat all the testing and adjusting. Finally, it will do as well as it's going to do, with some combination of the available parts and tuning variables. Maybe next Thursday night.



The trend of dynamometer design. Patraco, a manufacturer of modern highly-instrumented dynamometers furnished the photos and specs you see here, as an example of a sophisticated test installation. In addition to the electronic instrumentation of the dyno itself, auxiliary indicators such as head temperature and exhaust temperature are measured and displayed.

PATRACO
MARK III HIGH-PERFORMANCE
DIAGNOSTIC SYSTEM

STANDARD INSTRUMENTS
Digital Brake Horsepower Display 0–199.9
0–150 MPH Speedometer
0–150 Foot Pounds Torque
0–8000 Brake RPM
0–15,000 RPM Electronic Engine Tachometer
4-Channel Head Temperature 0–500°
4-Channel Exhaust Temperature 0–2000°
Automatic Calibration System

OPTIONAL INSTRUMENTS
Digital MPH Speedometer
Digital Torque

SPECIFICATIONS
Length–100′
Width (Frame)–52″
Width (Overall)–59″
Height (Platform)–8″
Height (Overall)–48″
Shipping Weight–1000 lbs.
Water Requirements–Std. 30-100 lbs., usage 5 GPM at 50 HP
Electrical Requirements–220 volts, single phase 15 amps

These tables are standard correction factors used to convert dynamometer readings to "standard temperature, pressure, and humidity" when an engine is tested under atmospheric conditions which are not standard. To obtain SAE corrected horsepower, multiply

Horsepower x A x B x C

Where A, B, and C are the corrections for non-standard altitude, temperature and humidity as shown on the tables. Inspection of the tables will show that the standard conditions are sea-level altitude, 60° F., and 0% relative humidity.

DYNO CORRECTIONS

ALTITUDE ABOVE SEA LEVEL	BAROMETRIC PRESSURE (ACTUAL)	CORRECTION "A"
ZERO	29.92	1.000
1000	28.86	1.035
2000	27.82	1.072
3000	26.81	1.115
4000	25.84	1.158
5000	24.89	1.200
6000	23.98	1.249
7000	23.09	1.295
8000	22.22	1.345
9000	21.38	1.400
10000	20.58	1.455
11000	19.79	1.514
12000	19.03	1.570

TEMPERATURE F.°	CORRECTION "B"
30	.972
60	1.000
70	1.010
80	1.018
90	1.028
100	1.037
110	1.046
120	1.056
130	1.065
140	1.074
150	1.083

RELATIVE HUMIDITY (AT 100°F.)	CORRECTION "C"
10%	1.008
20%	1.015
30%	1.020
40%	1.028
50%	1.035
60%	1.040
70%	1.048
80%	1.055
90%	1.062
100%	1.070

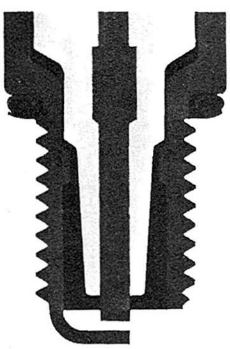
Design Symbols Used In NGK Spark Plugs

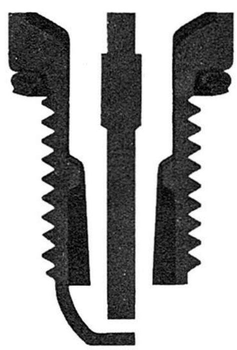
—PREFIX— —SUFFIX—

BP-7HS

BP	7	H	S
A: Thread 18mm ⌀	Heat rating numbers	**E**: Reach 19mm (3/4″)	**C**: Competition type
B: Thread 14mm ⌀	2 Hot	**F**: Taper seat	**M**: Special for Mazda Rotary
C: Thread 10mm ⌀	4	**H**: Reach 12.7mm (1/2″)	**N**: Racing type (Nickel electrode)
D: Thread 12mm ⌀	5	**L**: Reach 11.2mm (7/16″)	**P**: Racing type (Platinum electrode)
AB: Thread 18mm ⌀ Hex. 20.6mm	6	Blank 18mm ⌀ : Reach 12mm	**S**: Super wide range electrode
AP: Thread 18mm ⌀ Projected Insulator type	7	14mm ⌀ : Reach 9.5mm (3/8″)	**V**: Fine wire electrode
BP: Thread 14mm ⌀ Projected Insulator type	8		
R: Resistor type	9		
	10		
	11		
	12		
	13		
	14 Cold		

Crosscuts And Gap Styles Of Spark Plugs

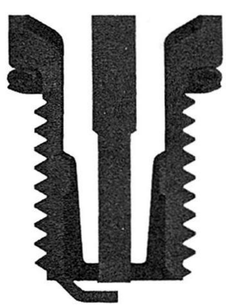

Standard Type


Projected Insulator Type

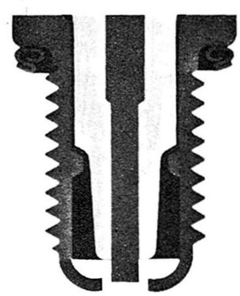

Racing Type


V Type


Taper Seat Type


Competition Type


Surface Discharge Type


Mazda Rotary Type

NGK Spark Plugs Conversion Chart

Standard type for automobiles, motorcycles, boats, trucks, snowmobiles, stationary engines, farm equipment, etc.

THREAD SIZE	HEAT RANGE	NGK STANDARD TYPE	NGK PROJECTED TYPE	CHAMPION Y = Projected Type G = Gold Palladium Electrode	AC S = Projected Type	AUTO-LITE	BOSCH	KLG P = Projected Type
18MM Reach ½″	Hot ↓ Cold	A-6 A-7 A-8		D23 D21 D16, UD16 D14, K15J D10 UK10 D9, D9J D6, K9 UK7, K7	C88 C87 C86, TC86 C85, TC85 C83, TC83 C82 C81	BT10 BT9 BT8, BZ8 BT6 BT4 BT3 BT2	M45T1 M95T5, M95T2 M145T1, M145T5 M175T1 M225T1, M240T1 M260T1	M30, M30H M50 M60, M60H M80 M100
18MM Taper Seat	Hot ↓ Cold	A-6F A-7F A-8F A-9F	AP-4F AP-6FS	870, F14Y, UF14Y 860, F9Y, UF9Y F11Y, UF11Y F10 F82 F62R, F62Y F60R, F60Y	86T, 85T, 85TS 84T, C84T, 84TS C83T	BTF6, BF7, BF82 BTF42, BF42 BTF3, BTF31 BTF1, BF32 BF703, BF22 BF601	MA95T1 MA145T1	MT30, MT50 TMT50
14MM Reach ⅜″	Hot ↓ Cold	B-4 B-6S B-7S B-7C* B-77C* B-8S B-9S B-10	BP-4 BP-6S	J14J, J14Y, UJ18Y J12J, UJ12 J11, J11J J13Y, UJ12Y, J11Y, J12Y J10Y, UJ10Y, J8, J8J J7, J7J, UJ8 J6, UJ6, J6J J5 J62R J4, J4J, J61Y, J60R J2J, J57R	C49, 46S 48, C47, C47W, M47 46, C46, M46 45, C45, C45W, M45, 45S 44, C44, M44, M44B, 44S MC44 43, C42-4, C43, 43S, MC42 M44C, M43 42, C42-1, M42 41	A82 A11, AT10, AZ9 A9, AT8, A9XM A7, AT6, A42 AT4 A3, AT3 A23 AT2 AT1 A901	W45T3 W145T3 W175T3 W225T3 W240T3	FS20 FS30, FS45P FS50, FS55P FS70 FS75 FS100 FS100-2
14MM Reach ⁷⁄₁₆″	Hot ↓ Cold	B-4L B-6L		H12 H11 H10, H10J, H18Y H8, H8J H14Y	47L 45L, C45L, TC45L 43L, C43L, C43LY	AL11 AL9, ATL8 AL7, A7 ATL4, ATL3	W125T4	FA50, FA50H FA70
14MM Reach ½″	Hot ↓ Cold	B-4H B-5HS B-6HS B-7HS B-7HC* B-77HC* B-8HS B-8HCS* B-9HS B-9HCS* B-10H	BP-4H BP-6HS BP-7HS	L14, UL15Y, L10 L90 L86, L85, L95Y UL12Y, L88 L7, L87Y, UL87Y L81, L82Y, UL82Y L5 L62R L4J, L64Y, L66Y L60R L57R	46FF, 46FFS, 45FFS, 45FF 45F, M45FF 44FFS, 44FF, M43FF 44F, 43F, 43FFS 42F, 42FF, 42FS M42FF, MC42F	AE52, AE6 AE4, AE42 AE3, AE32 AE2, AE22 AE903 AE603	W95T1 W145T1 W175T1, W175T7 W200T7, W200T35 W225T1, W225T35 W225T7 W240T1, W240T16 W260T1 W270T16 W280M1 W310T16	F20, F50 F55P F70, F65P F75 F80 F100
14MM Reach ¾″	Hot ↓ Cold	B-4E B-5ES B-6ES B-7ES B-7EC* B-77EC* B-8ES B-9ES B-10E	BP-4E BP-5ES BP-5ESL BP-6ES BP-7ES BP-8ES	N21, N16Y N18 N8, N14Y, N13Y N84, N88, N6, N12Y, UN12Y N11Y, N10Y, N5 N9Y, N8Y N4 N62R N6Y, N7Y N3 N60R, N2	47XL 46XLS 46N, 46XL, 45XLS 45N, 45XL, C45XL 44N, 44XL, 44XLS 44XLS, 43XLS, 43N, 43XL C42N 42XL, 42XLS 41XLS	AG9 AG7, AG52 AG5 AG4, AG42 AG3, AG32 AG2, AG23 AG701	W95T2, W125T2 W145T2 W145T30, W160T2 W175T2, W175T30 W200T27, W200T30 W225T2, W230T30 W240T2, W240T28 W250P21, WG250T28 W260T28, W265P21 W280M2, W300M2	FE20 FE30 FE50, FE45P FE70, FE55P FE75 FE80, FE65P FE100 FE220 FE250
14MM Taper Seat	Hot ↓ Cold		BP-6FS BP-7FS	UBL13Y BL11Y BL7Y, BL9Y	46TS, 45TS 44TS 43TS, 42TS, 40TS	AF52 AF42 AF32	WA125T40 WA200T40	
12MM Reach ½″	Hot ↓ Cold	D-4H D-5HS D-6HS D-8HS D-10HS		P-8Y P-7 P-6	S124FS S122F S121F	HE3 HE2 HE1	X175T1 X260T1 X300T1 X320T1	TW270 TW275 TW280
12MM Reach ¾″	Hot ↓ Cold	D-4E D-6ES D-7ES D-8ESL D-8ES D-10ES		R-6	S123XL S121XL		X240T17 X270T17 X300T2	
10MM Reach ½″	Hot ↓ Cold	C-4H C-6H C-7HS C-9H C-10H		Z-10 Z-8 Z-6	S104F S102F	PE3	U175T1 U260T1	T30 T70 T90
14MM Special		BM-6A BM-7A BM-6F BM-7F BL-6	BPM-7A	CJ8 CJ6 DJ8J DJ6J TJ8J, TJ6J	CS45 CS42 CS45T CS42T C47W, C45W		WKA175T36 WKA225T6	
7/8″—18 Reach 5/8″	Hot ↓ Cold	F-23 SA104		W20 W18, C16C W14 W10	C78L, C77 C77L, 76, 78S C75, C74 C73	TT10 TT8 TT4	Z23T2 Z45T1 Z120T1 Z145T1	AL20 A5 A20, A30
1/2″ Pipe		H-26 HD-20		34, 33, 32, 30 A-25	G59, G56, G58	F11		

*Competition Types (Shorter Side Electrode).

Courtesy NGK Spark Plugs (U.S.A.) Inc.

NOTE: This chart is furnished as a guide. Due to differences in design and material, plugs produced by various manufacturers do not have exactly the same heat range.

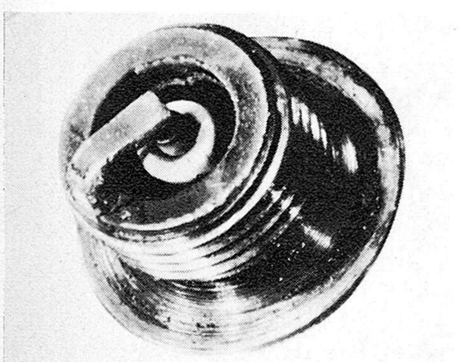
PLUG READING

In addition to making the spark, plugs serve the important purpose of telling the tuner what has been happening in the engine. They are sensitive to temperature and, if read properly, are a good indicator of temperatures in the combustion chamber.

Under any fixed operating condition, plug temperature is largely determined by F/A ratio, and the condition of the plug is an indication of mixture.

If you take five plugs which look slightly different, and show them to ten people for analysis, each plug will likely get two votes for being "right." Plug reading is not an exact science. The reassuring part of this is that you can learn to read plugs as well as anybody. The more you do of it, the better you get.

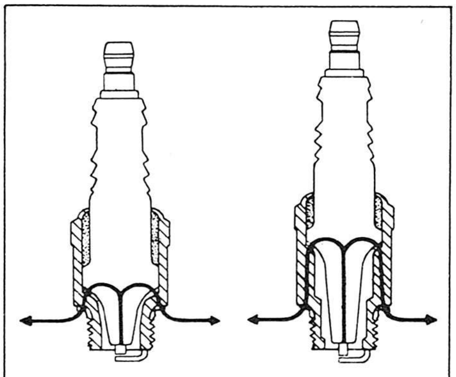
The first part is to learn where to look. Recently, I watched a fellow changing plugs and saw a big pile of used plugs on his workbench—all burned up. He was putting in new plugs of the same type number as those which he had been destroying with monotonous regularity. He had been "reading" the burned plugs, but had been looking in the wrong place, so thought they were OK. He was also very perplexed about why he had to replace perfectly good plugs so often.



You look at the ceramic insulator which surrounds the center electrode of the plug. This is round, generally cone-shaped, is exactly in the middle of the hole in the bottom of the plug. The center electrode (wire) passes through the center of this insulator.

Because it is nonmetallic, the insulator is both a poor conductor of electricity—which is its purpose—and a poor conductor of heat. Because it extends downward from the metal body of the plug, there is a relatively long path for heat flow from the tip of the insulator back to some metal where it can get rid of heat. Some heat will flow up through the center electrode, however this is a long skinny path and may not be solid metal all the way. So the center electrode does not dissipate a lot of heat either and it and the insulator surrounding it tend to get hot together.

Since engines, according to their design and intended use, will have different normal temperatures in the combustion space, spark plugs are made in different heat ratings. The rating is an indication of how well it can cool itself by conducting heat up through the center insulator. A long insulator has a longer path for heat flow and will tend to retain heat longer and rise to higher temperatures.



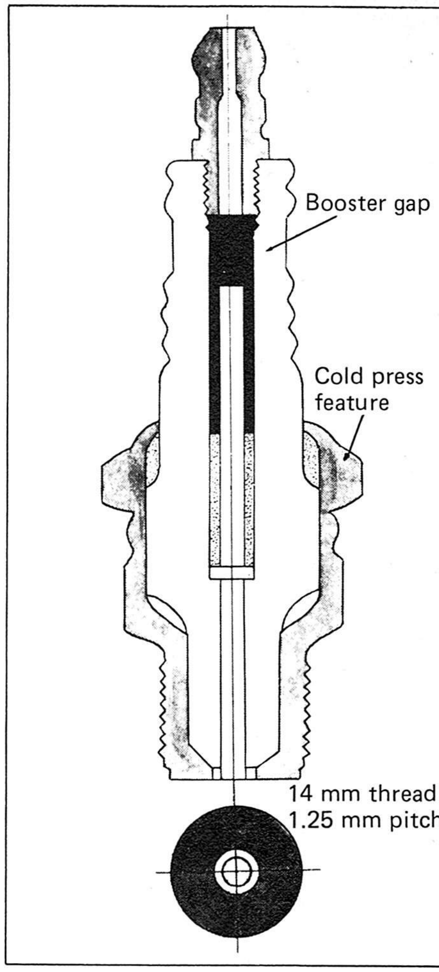
COLD TYPE (Short Heat Path) HOT TYPE (Long Heat Path)

Cold plugs have shorter insulators, get rid of heat faster, and tend to run cooler. An engine being run under high loads and open throttle generates more heat and requires a colder plug.

The nomenclature can be confusing, particularly if it is thought that spark plugs somehow manufacture heat in the engine. The only energy brought into the engine by the plug is the spark itself. This is flea-power and does not contribute any significant amount of heat.

Spark plugs do not make heat. They are victims of the heat in the engine and become hot due to the heat of combustion. Under fixed operating conditions, with some fixed amount of heat being produced by the combustion process, a cold plug will operate at a lower temperature than will a hot plug.

The heat rating of a plug (cold or hot) is indicated by the numbering scheme used by the manufacturer. A few minutes spent with a spark plug chart will disclose the scheme used for the brand of your choice.

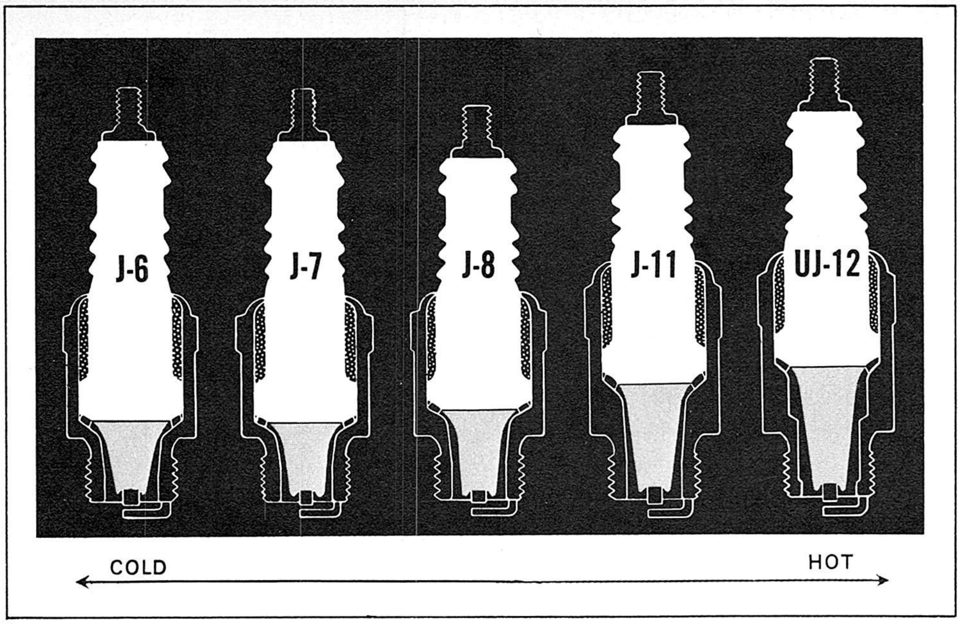


A type of plug often used with electronic ignitions is the *surface gap* type, shown above.

The ignition spark travels radially from the center electrode to the round, threaded, metal shell of the plug, taking any path it chooses. The insulator is flush, or nearly flush, with the tip of the plug. The spark, effectively, travels along the surface of the insulator, hence the name.

Because very little of the insulator is exposed, and because most of the insulator is in close contact with metal, surface gap plugs have very cold ratings. This allows use in high-performance engines with less chance of the plug becoming hot enough to start preignition.

A cold plug, in an engine which is not ridden hard, tends to foul, however the rise time and high voltage of electronic ignitions gives them the ability to fire plugs with a considerable amount of fouling present.



This drawing shows both construction differences and a numbering scheme to indicate plug heat ratings.

Courtesy of Champion Spark Plug Company.

OPERATING TEMPERATURES

The reason for all this attention to spark plug temperatures is to allow the designer or tuner to find a plug which will operate between two temperature limits over the normal ranges of combustion temperatures in the engine.

The lower limit for plug temperature (of the tip) is about 700°F. At this or higher temperatures, the insulator will burn off carbon, deposits from some fuel additives, and wet oil or gasoline. If these deposits are not burned off, they can foul the plug.

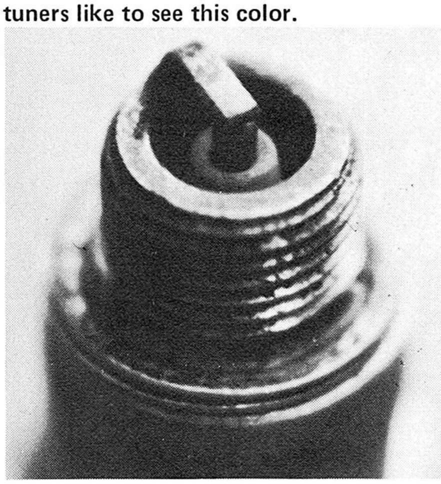
The higher limit is about 1,700° at which point the plug is likely to be hot enough to cause preignition. The trick is to find that plug which will stay within limits in a particular engine, the way it is being operated.

Because the combustion process puts deposits on the plug, and because the plug burns them off in proportion to the temperature it has reached, there is a visible indication of plug temperature which is obtained by looking at the plug.

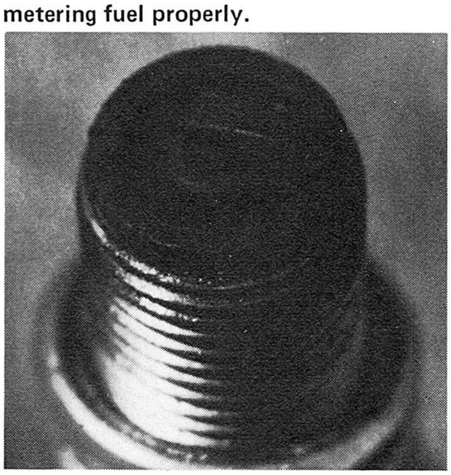
This is a continuing process. The deposits are continually being thrown at the insulator, and the insulator is continually burning them off. Therefore, in order to know what the plug has been experiencing, it is necessary to allow enough time for conditions to stabilize.

It is necessary, before reading a plug, to first prepare it by running the engine at some steady condition for a minute or so.

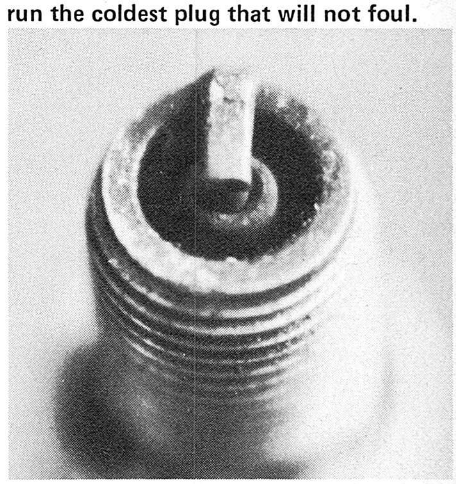
Insulator of this plug is slightly darker than new condition. This is acceptable and many tuners like to see this color.



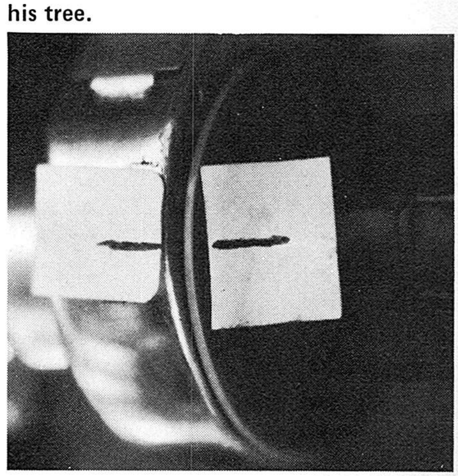
Oops! Too rich or too cold. This plug came out of a two-stroke which would run only at full throttle. Problem proved to be carb needle jet loosened by vibration and not metering fuel properly.

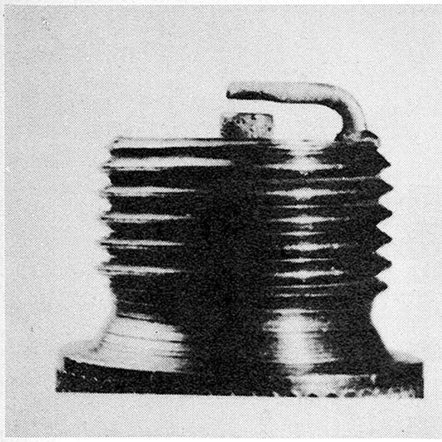


Insulator darker yet, but no sign of oil or soot fouling. In general, it is desirable to run the coldest plug that will not foul.

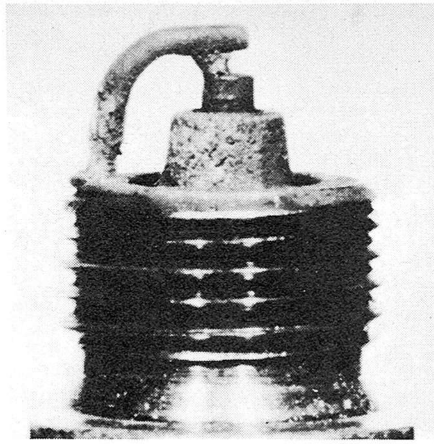


Brilliant method of locating half-throttle position for repeated test runs. Stick tape on throttle housing and throttle grip. Marks come into alignment at mid-throttle. Inventor of this technique, being denied world patent rights, glumly returned to his tree.

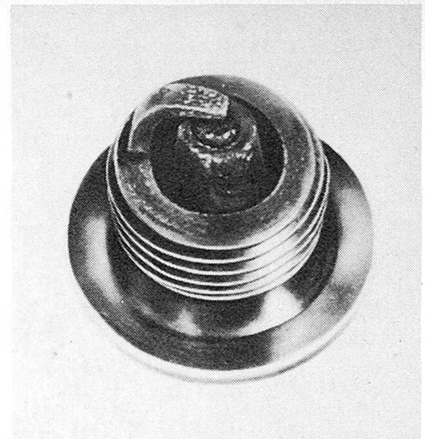




Wrong polarity. Depending on the direction of electrical current flow during the spark, one or the other of the two electrodes will slowly lose metal. The center electrode, having more area, can better afford this loss. Photo shows electrical erosion of side electrode which shortens plug life and makes regapping necessary more often. If the bike is built this way, there is usually not much you can do about it.



Bridged gap. Popular among two-strokes, possible on any bike. Symptom is bike immediately stops firing the cylinder with this spark plug. If bike has only one cylinder, symptom is dramatic. Cause is mysterious. Dirt particles in cylinder will often bridge the gap. Also additives or components of gas and oil. Cure is to remove bridge, regap.



Worn out. Notice side electrode is eroded some and center electrode is eroded a lot. Indicates correct electrical polarity, if that's any comfort. This plug should have run a long time and deserves retirement.

These photos, courtesy of Champion Spark Plug Company, show interesting things that you mainly want to see on somebody else's spark plugs.

A full-throttle reading is obtained by running the bike, at full throttle and preferably up a slight hill, for a minute or two. Then, as quickly as possible, the throttle is closed, the clutch pulled in, the engine switched off, and the bike is coasted to a stop.

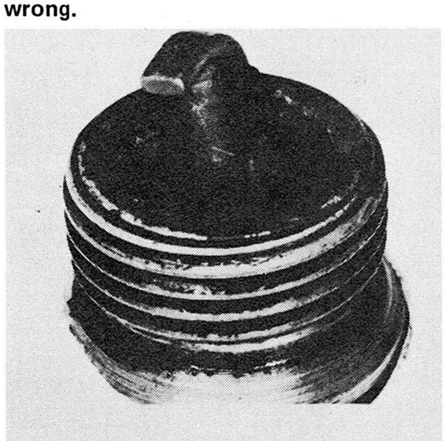
The plug is then removed and examined by looking at the center insulator. If there is wet fuel or oil, the mixture is obviously far too rich. If the color is dark, such as black or chocolate color, the mixture is also too rich.

Colors between cocoa and light tan or grey are acceptable.

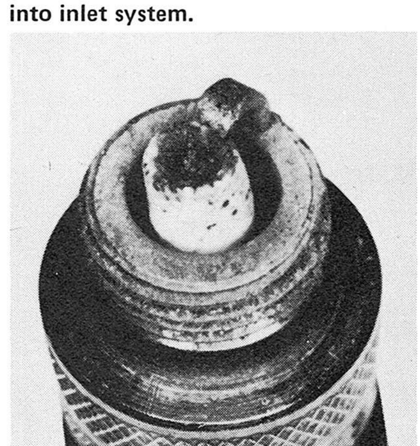
If the insulator is like new, white or pink depending on the new color of the insulator, it has been too hot. If the insulator is blistered or glazed by heat, or the electrodes have melted, preignition and/or detonation were either happening or imminent.

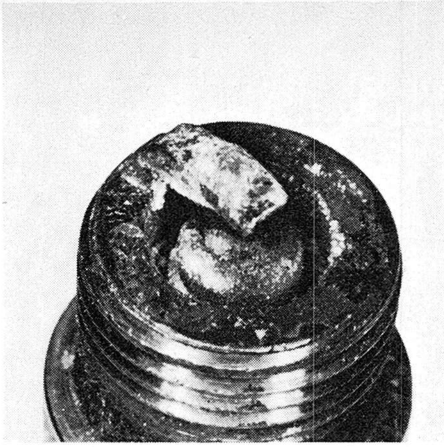
Readings can be taken at half throttle the same way as at full throttle, the difference being simply how far the throttle is held open for the test.

Mechanical damage. Something whacked this plug hard. Cause usually mysterious because owner will not admit what was wrong.

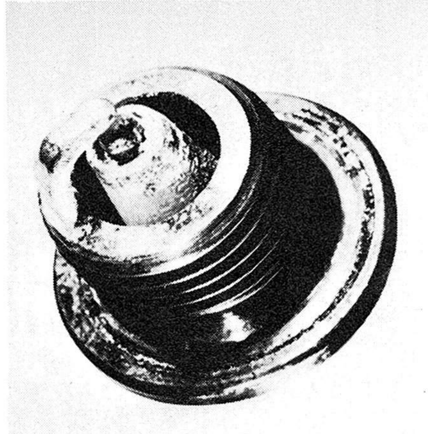


Burned. Center insulator, except for metallic deposits is burned white and glazed due to excessive heat. Electrodes are melted. Possibly piston is also melted. Likely cause, pre-ignition or excessively lean mixture. Possible massive air leak into inlet system.





Gas-additive fouling. In two-strokes, also possibly oil-additive fouling. This stuff is often yellow or grey, sometimes powdery, and will flake off or rub off easily. This material usually is not conductive and doesn't hurt much except appearance. Clean and continue to use plug. Consider another brand of gas or oil.

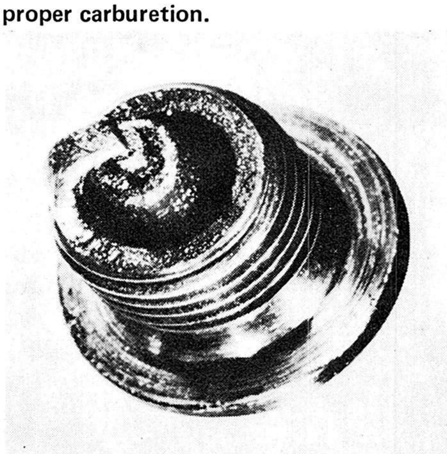


Burned again.

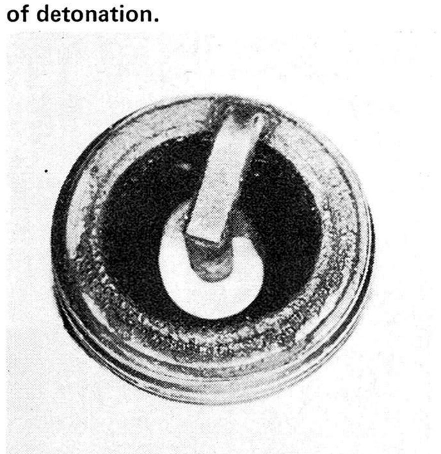
PLUG INSTALLATION TORQUE LIMITS (FT/LB)

	Aluminum Heads	Cast Iron Heads
10 mm	7	8
12 mm	10	10
14 mm	14	18
18 mm	18	20

Fouled. Mixture too rich or plug too cold. If it is mixture, fix it. If you are thrifty and this plug will fire at all, you can clean it by running full throttle a while with proper carburetion.



Very bad news. Insulator broken. Could have been done by denizen of trees trying to adjust gap. If not, then likely evidence of detonation.



The tuner has a dual concern about the F/A ratio. He wants a mixture which will give best power and also one which will cool adequately. If the engine is properly designed, maintained, and operated as intended, it should be possible to satisfy both requirements.

MEASURING AIR DENSITY

The hardest way to "measure" air density is to calculate it from known values of temperature and barometric pressure. The formula is:

$$D = \frac{1.33\,P}{460 + F}$$

where D is air density in pounds per cubic foot, P is actual barometric pressure in inches of mercury (not what the weatherman says), and F is the temperature in degrees Fahrenheit. The denominator of the fraction is actually degrees Rankine.

METER

An easier way is to use an *air density meter*. Basically, this meter solves the equation above, and displays the result as a percentage of sea-level density at 60°F.

Ignition contributes to engine power mainly in a negative sense—Poor ignition will reduce engine power, however the best that can be done is to make it right. Champion Spark Plug Company makes this point very well in their excellent little booklet, "Racing Heat Range Chart and Tuning Guide."

"A claim of an appreciable gain in horsepower due to the installation of 'revolutionary' plug designs or ignition systems is usually unfounded. This gain in the true connotation is *recovered* horsepower. Maximum horsepower has been *restored* to the engine by adequate ignition, enabling the RPM level to be re-tailored to the camshaft range and exhaust tune.

"(If the engine gained 18 horsepower on the dyno, this horsepower was already in the engine . . . the 18 horsepower was not supplied by the new ignition components.)

"Measurable horsepower gains are generally derived from precise ignition timing ('spark curves'). Spark plug gap style and location can also give significant improvements in horsepower and engine responses."

The main precautions in using an air density meter are to treat it like a precision instrument and to avoid taking readings when it is heated above actual ambient air temperature. Improper density readings will result if the meter has been in direct sunlight, or perhaps in a heated automobile.

RAD CHART

The way to get air density with minimum figuring and expense is to read it off the RAD chart in this book. Rather than scurrying back to page 16 to see what it looks like again, look inside the back cover.

MEASURING TIMING

To measure spark timing, you must do two things:

- Observe the spark, or observe some indication that the spark is happening at that instant.
- Observe flywheel position, piston position, or some other reference to find out where, in the engine cycle, the spark is happening.

TIMING LIGHT

The handiest way to do both of these things is to use a timing light. The best kind of timing lights are called "power" timing lights, or strobe lights.

All timing lights connect to a spark-plug wire, using some kind of an adapter to make a connection inside the spark-plug connector on the end of the wire. If there is an ignition distributor, this connection may also be made there.

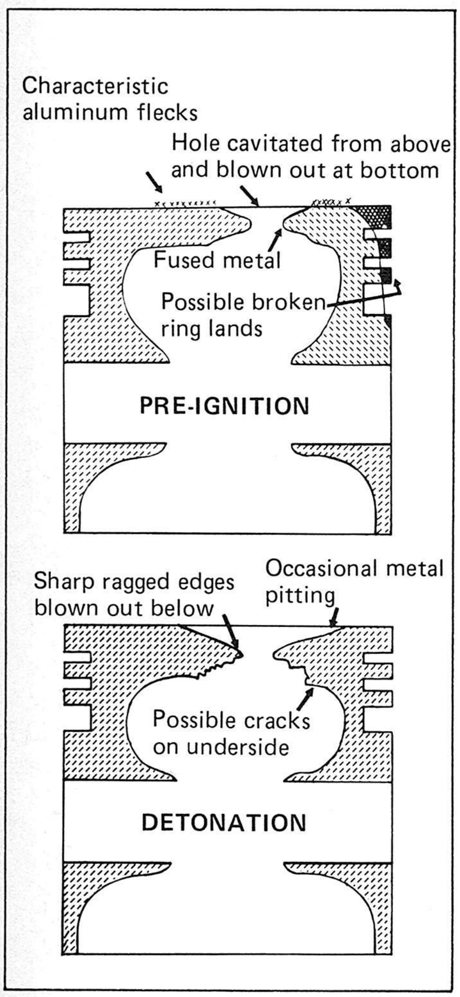
The pulse of electrical energy delivered to the plug is sensed by the timing light and it makes a bright flash at the same instant. Timing lights are used with the engine running.

Cheap timing lights use the energy of the spark pulse in order to operate the light source in the flasher. This makes a dim light and sometimes extracts so much energy from the spark that the engine will not run.

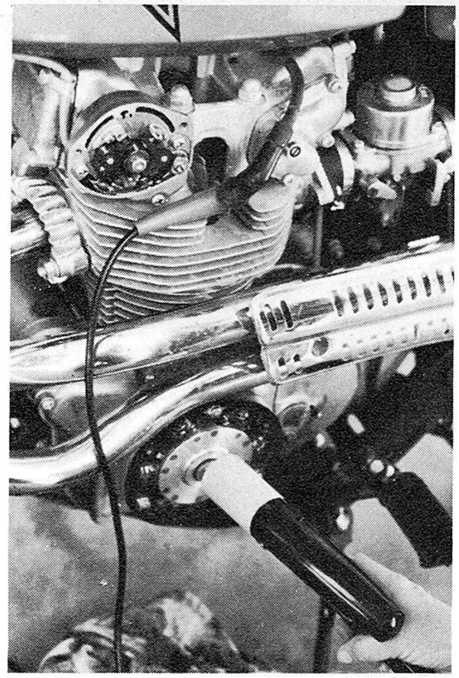
The power timing light uses only a tiny bit of the spark energy from the ignition system and uses it only as a trigger. The trigger signal operates an electronic circuit inside the timer, which in turn makes the flash. The power for the flash is drawn from the timing light itself, rather than from the ignition under test.

Power timing lights use either internal batteries or have a line cord which connects to an AC electric outlet. For tuning away from commercial power, the battery-operated timing light is more useful. They also cost more.

Since timing lights are used with the engine running, it is obviously not possible to remove the spark plug and measure piston position. The tim-

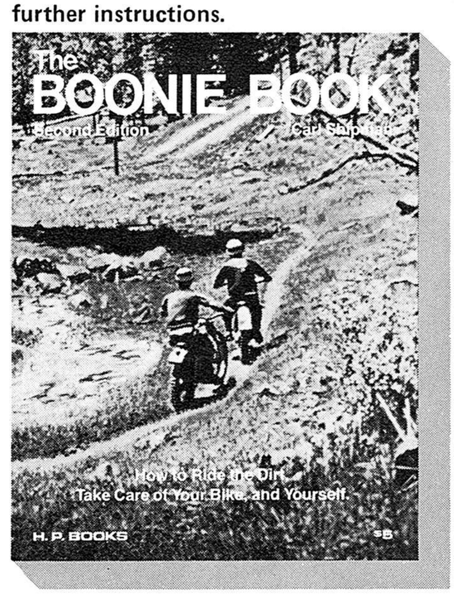


More horror stories . . . These drawings by Champion provide clues as to why piston failed. Heat of pre-ignition tends to leave evidence of melted metal, weakens ring lands.
Hammer-blows of detonation tend to leave broken edges and cracks in metal.



Power timing light ready for use on Honda. Coil spring adapter fits on end of spark plug, plug cap fits on end of adapter. Test-clip from timing light is attached to adapter on spark plug and thereby senses spark. Caution! Don't touch! The timing light makes moving parts appear to be stationary. If you put a finger in, you may not get it back!

While fixing your scooter, take a break and look at the pretty cover of THE BOONIE BOOK. Dream a little about off-road fun and then get back to work. When bike is tuned, read "Boonie" for further instructions.



ing indication must be a mark on the flywheel or some rotating part of the engine, which aligns with a corresponding mark on the engine case. If the engine does not have such marks, the tuner must provide them.

Assuming the timing reference marks are there, and the timing light is used to illuminate them, the light will function as a strobe. It will flash once for each spark and the flash will be of very short duration. The effect is to stop motion, the same way a camera stops a moving object. The strobe light does this repeatedly, once each spark, and the reference marks should appear to be stationary. If they are seen to be in alignment, then the timing is correct. If not, then the timing must be adjusted.

Measuring timing with the engine running has other advantages. If there is a spark-advance mechanism you can watch it work and check timing at both low and high RPM. If there is a tach, and a scale of timing marks, the advance can be checked at different RPM and compared to the desired curve or spec.

When the spark is observed with the engine running, sometimes cutting-out at high RPM can be observed. If the timing is irregular, the rotating mark will appear to jump around with reference to the fixed mark. This indicates mechanical problems such as a wobbling shaft, loose bearings, or a sticking advance mechanism.

For serious tuners, a power timing light is the only way to measure ignition timing. There are other ways.

MAKING YOUR OWN

Sometimes timing reference marks on an engine will display a scale, ranging five or ten degrees in each direction from the stock setting.

On some bikes, there is a single pair of marks, and in some cases, none at all.

It is not difficult to make your own marks and, if you are going to test different timings, you need to have some fairly accurate way to know what the timing is, so you can observe and record it.

For the stationary mark, you can mark with a pen or a pencil. More permanent marks can be made by careful use of a chisel or punch, lightly tapping a mark into the case at some convenient place. Or, you can fabricate a pointer and attach it under a screw head. The fixed mark can be expanded into a scale, but this is usually not convenient. It is easier to put the scale on a rotating part, such as a flywheel.

In making a scale, it does not matter if the intervals are degrees, inches, or metric, as long as they are uniform, easy to read and reasonably close together.

However, since most data on tuning is in degrees, it is comforting to know your settings in degrees. Degree markings, around the perimeter of a circle, are farther apart, of course, as the diameter of the circle is made larger.

On page 116 is a chart which you can use for degree-spacing on flywheels of different sizes. The marks can be scribed or punched onto the rotating part, however it is usually not a good idea to hammer around magnets or bearings. It is simpler and better to make the scale on a piece of tape and then stick the tape where you want it.

Another decision is where to put zero. You can find TDC and arrange the timing scale so that zero on the scale coincides with the mark on the case at TDC. This will cause the scale readings to be in degrees BTDC, as the specs are written.

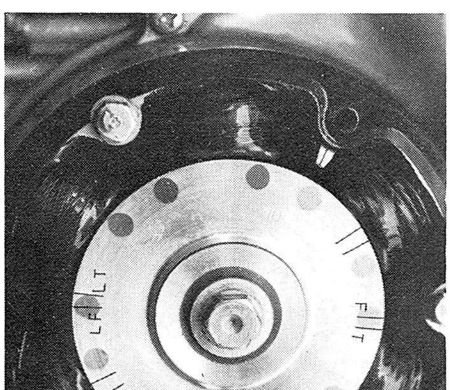
Or, you can put zero at the stock timing and then read the scale for degrees ahead of or behind the stock setting.

You also have to know the direction of rotation when the engine is running. Usually flywheels are marked with an arrow to show this. If not, rotate the engine in the normal direction (with the plugs removed) and mark the flywheel with an arrow. The kick starter or electric starter will rotate the engine in the normal direction.

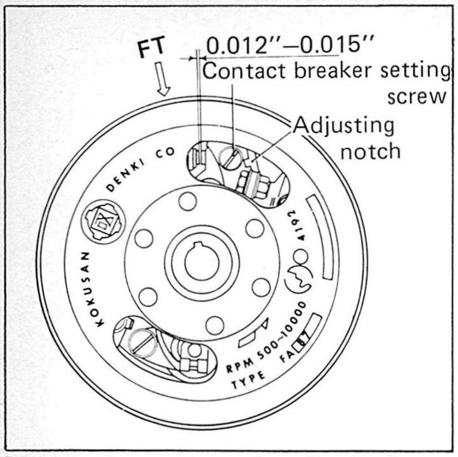
With all of this done, you can then interpret what you see with the timing light, or whatever method of measurement you are using. If the mark on the rotor is ahead of the case mark, rotationally, when the spark occurs, then timing is early, or advanced too much.

PEEKING

The crudest method of observing point opening, in order to know when the spark is happening, is to look. Rotate the engine by hand and watch the points. When you think you see them just open, note the timing reference marks. This method will often get a sick bike running well enough



Timing marks on Honda generator rotor. Marks labeled LF and LT are for left-hand cylinder of twin-cylinder engine. Marks F and T are for right-hand cylinder. Marks T are for valve timing. Marks F are for ignition timing and show static advance when in alignment with pointer on case. Ignition advance is shown by pair of marks which are 32° advanced from each of the F marks. When fully advanced, timing light should allow pointer in between the two advanced-timing marks.



Possibly the most prevalent flywheel magneto in the world. This unit is used on zillions of Japanese motorcycles.

to ride it home but is not otherwise recommended.

A slightly better, rough and ready method is to open the points by rotating the engine, insert a thin strip of cellophane between them, turn the engine backwards until the points grasp the cellophane, and then rotate the engine in the normal direction until the points just release the cellophane.

If you are working on a flywheel magneto, it's hard to see what's going on, through the little hole in the flywheel. If you are trying to observe point opening, the flywheel must be in place, otherwise the cam isn't there to operate the points.

A visual or audible indicator works best.

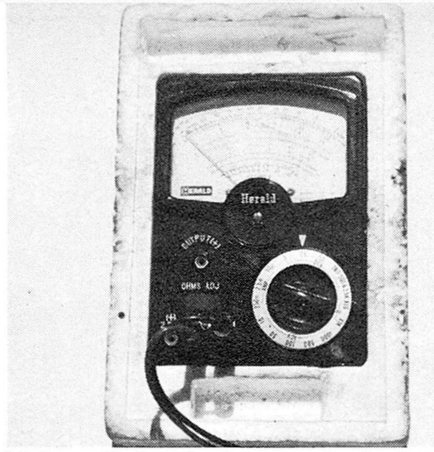
OHMMETER

Another satisfactory method, for flywheel magnetos, is to use a sensitive ohmmeter, capable of displaying a resistance change of around 0.01 ohm. These are moderately expensive, however they are useful for other purposes as well.

LIGHT BULB

On a machine with battery ignition, a good tester is simply a flashlight bulb, of the proper voltage, with two wires connected to it. Clips on the ends of the wires are attached to the point set, one on each side. Or, one to the movable point and one to ground.

With the ignition on (but the spark plug removed) the engine is rotated. As long as the points are closed, they short out the light bulb and it does not glow. When the points open, battery voltage appears across the bulb, and it will light.



I left my little volt-ohmmeter in the foam packing which protected it all the way from Japan. As you can see, it protected it also from dog bites and falling motorcycles. As a general service tool, provided you know how to use it or learn how, a little meter like this is very useful.

With flywheel magnetos, there is of course no battery in the system. Some testers use a flashlight battery in series with a light bulb and test leads. When this is connected across the points, and the points are closed, they complete the circuit and the battery causes the light to glow. When the points open, the light intensity is supposed to change. The light will not go out because both the ignition source coil and the primary winding of the spark coil are in parallel with the points. These coils have low electrical resistance to direct current (battery current), so the current through the bulb is nearly the same whether the points are open or closed.

The light bulb will flicker at the instant the points are opened, however it is hard to see and, if you are looking closely at the light, you cannot watch the timing marks.

A solution is to disconnect wires from the movable point, to isolate it electrically from both coils. In some cases, this is not convenient to do.

Lest we lose sight of the goal, while considering all these methods, the basic problem is still simply to observe the spark in some way, while also observing the position of the piston.

DIAL INDICATOR

Many factory manuals use piston position as the basic reference, sometimes allowing you to transfer the reference out to an external pointer after you have verified that the pointer is correctly located.

The drawing on page 113, courtesy of Norton Villiers, shows a way to time an AJS. A dial indicator is screwed into the spark-plug hole, TDC is located, and then the engine is turned backward to the firing point.

A battery bulb is connected to the point set (note the disconnected wire) and the points are adjusted to make the light just flicker off.

If the points don't move while everything is being tightened down, this sets timing exactly to spec. It should be checked again after tightening the screws.

MEASURING ELECTRONIC TIMING

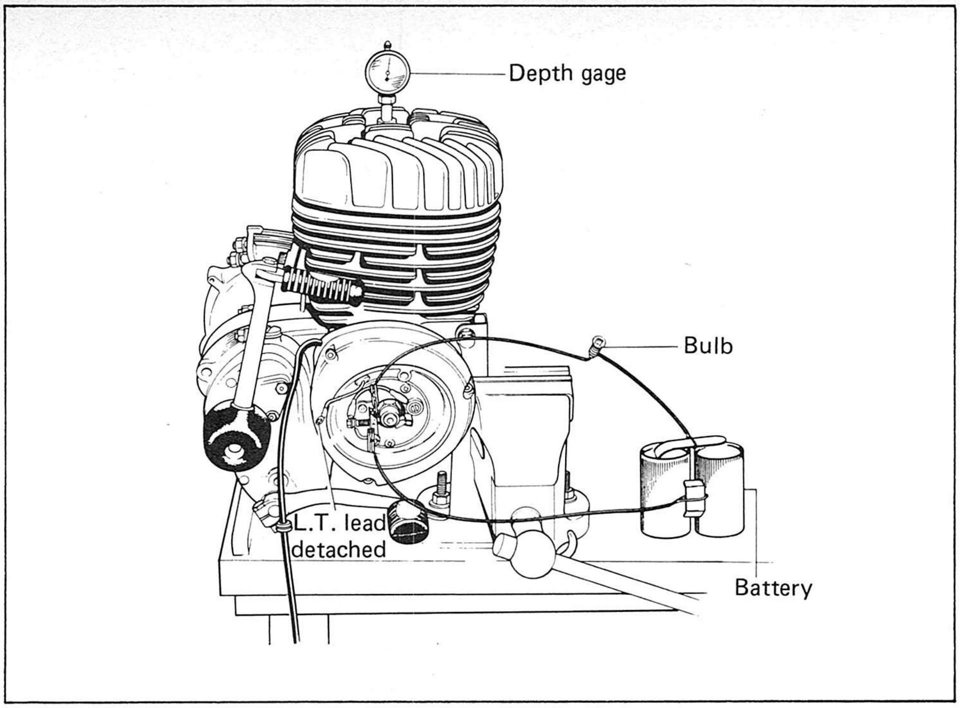
Magneto-electronic ignitions may have marks on the flywheel and case to show stock timing. If not, they may have a hole in the flywheel which comes into alignment with a hole on the stator. Alignment is checked by inserting a pin into both holes.

IGNITION ADJUSTMENT

Firing point:	2.5 to 3.0 mm (0.098 to 0.118 in.) before top dead center
Contact-breaker gap:	0.4±0.005 mm (0.016±0.002 in.)
Pole separation:	22 to 55 mm (0.966 to 0.984 in.)

Two marks are punched in the magneto flywheel: "O" corresponds with the line marked on the housing when the piston is at top dead center. "M" indicates the ignition timing point.

This spec, for a Sachs engine is typical of single cylinder two-strokes. It states timing by piston position, point gap, and a spec for the distance between magnet and coil in the magneto, at the time of firing.



A few flywheel magnetos are arranged so that the cam and points are external to the flywheel, as shown here. The flywheel and the source coils are behind the cover on which the points are mounted. This is very handy.

In the latter case, alignment of the holes in rotor and stator is not an indication of timing. It simply shows the relationship between the flywheel and the coils on the stator at the time the spark happens. The stator will normally be movable, and its position must be set for proper timing in relation to piston position.

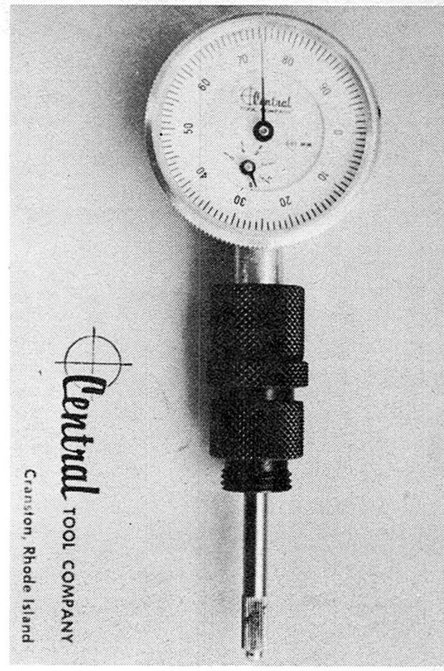
A timing scale on the stator, referenced to a mark on the case, is an indicator of spark timing with respect to the engine cycle.

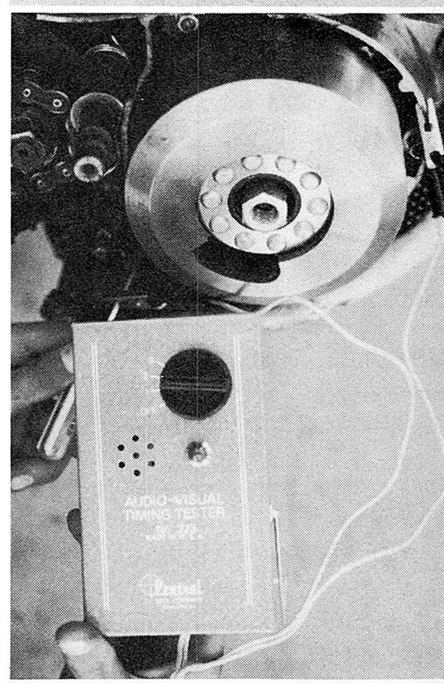
Battery-electronic ignitions usually have marks on the rotor and a pointer or mark on the case. Frequently it is advised that the tuner check to see that the pointer is correctly located before depending on it for timing. The check is to use a dial-indicator in the plug hole as described earlier.

MEASURING COMPRESSION

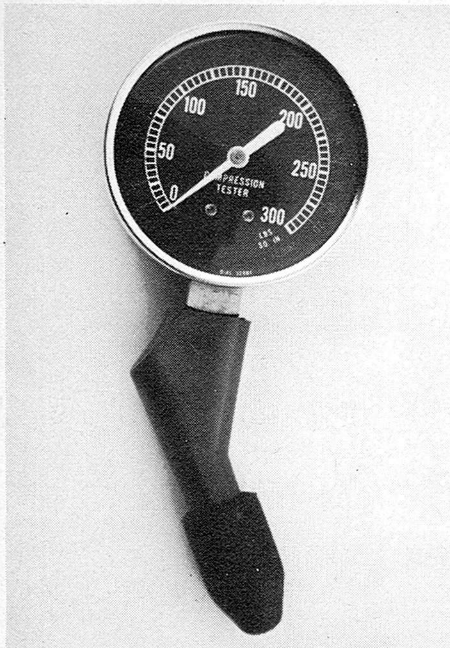
The simplest way to get an indication of engine compression on a bike with a kick starter is to observe how hard it is to kick over. When this becomes noticeably easy to do, it is time to fix the bike. Obviously this is crude and before you will notice any change in kick power the engine power will be very poor.

Another crude way is to remove the spark plug, put your finger over the hole, and crank the engine. You calibrate your finger so it can measure the pressure. The best way is to use a compression gage which is simply a glorified tire-pressure gage. These may have a cone-shaped rubber ring on the end, which you press into the spark-plug hole, while cranking the engine with throttle fully open and ignition off. Some compression gages have an expanding connector which fits into the spark-plug hole and then expands so you don't have to press it down tightly. Others have a short length of hose with a screw attachment on the end which fits into the plug hole. A gage with a short hose on it is a little more convenient to use but it may read a bit low on account of the volume of the hose which becomes part of

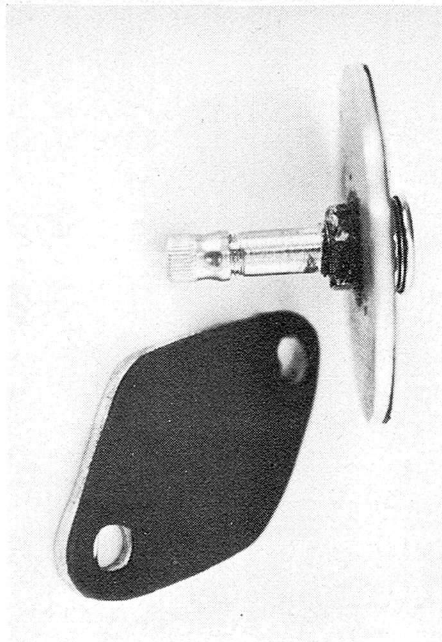




These two instruments do the job. The dial indicator has a rotating scale to allow easy zeroing at TDC without a lot of arithmetic. Central Tool Company also makes a clever adaptor to allow this indicator to be used on heads with inclined spark-plug holes. The "buzz-box," Central Tool's Audio-Visual Timing Tester, offers both a light bulb and a buzzer. Note one wire connected to the engine case. The other lead is clipped to a screwdriver so it can be held against a terminal where the "hot lead" from the ignition connects. When the points open, the buzzer changes its note. It is not necessary to disconnect any wires when using the buzzer.



Cylinder compression tester is held in spark-plug hole while engine is cranked.


Simple case-compression tester can be fabricated for about a dollar. Tire valve-stem is type used for tubeless tires. Variety used on truck wheels screws in place as shown. Black goop is extra sealant. Round plate (with air valve) blocks off exhaust opening and is held in place by exhaust nut. Any clamping method will do. Oblong plate is inserted between carb and inlet. Both plates have rubber gasket glued in place.

the minimum volume of the combustion chamber while testing.

Whatever type of compression gage you use:

- Remove one spark plug from each cylinder. If a cylinder has two plugs, leave one of them in place.
- Be sure the ignition is off.
- Attach gage.
- Open throttle all the way.
- Crank the engine a few revolutions with foot power or starter motor.
- Take the highest reading after the reading has stabilized.

CRANKCASE COMPRESSION

On two-strokes, there is also crankcase compression to worry about. People usually don't bother to check it until there is some indication of leakage.

The test is to seal off the inlet, exhaust, and spark-plug openings and pressurize the entire engine to about 6 psi. Then, the decline in pressure is observed on a gage. A leak rate of less than one pound per minute is considered OK. You can also listen for leaks and use the old soapy-water trick.

There are commercial case-testers available, or you can make one without much effort, using a low-pressure tire gage for the indicator and a tire pump to create the pressure. The precaution, when using a tire pump to pressurize the case, is not to overdo it. It is easy to pump more than 6 psi and the case seals may be damaged.

A common cause of reduced case compression is the seals on the ends of the crankshaft. If the seal on the ignition side leaks, it will allow mixture to escape and air to be drawn in, leading to a lean F/A ratio in the combustion chamber. Result will be excess heat, burned spark plugs, and possibly engine damage. When it appears that your carburetor has magically changed its main jet, suspect a case leak.

On the clutch side, a defective seal can allow mixture to escape which may make bubbles in the oil. The bubbling may be audible if you listen at the filler cap. On the vacuum phase, oil may be drawn into the engine with excess smoke as a result. If the clutch and transmission use the same oil supply, both clutch and transmission can eventually be drained dry by this process.

Gaskets, such as cylinder-base, case-joint, or cylinder-head, may also cause the problem. Rarely, a pinhole in the engine casting will open up and cause a leak.

WHY DOES A COMPRESSION GAGE READ HIGHER THAN WE THINK IT SHOULD?

The 450 Honda has a compression ratio of 9:1. If it actually compressed this much, and took in sea-level air at a pressure of 15 psi, the resulting pressure in the cylinder would be nine times as high—135 psi.

In atmosphere, pressure gages read zero when they are not connected to anything. Consequently, a gage will always read one atmosphere less than the absolute pressure.

So, a gage, exposed to a pressure in the cylinder of 135 psi, would read 120 psi.

But, the shop manual says the compression tester should read 185 psi. Normal cylinder pressures, as read by a compression gage at cranking speed of the engine are usually higher than the CR would suggest. There must be a reason.

Recently, we overheard a gentleman observe that his engine must be running a CR of 22:1, because he had measured compression and it was about 22 times atmospheric pressure. This is not likely.

The reason is a little complicated, but knowing it can save you from errors like the above.

When a gas is compressed, two things happen. First, the pressure goes up exactly as much as the volume goes down. In other words, the pressure increase is equal to the compression ratio.

In addition, due to the mechanical work invested in compressing the gas, heat is generated. A tire pump gets hot as you use it.

In considering the operation of an engine, we have assumed that first the mixture is compressed, and then it is heated by combustion. In fact it has also been heated some by compression, which simply adds to the temperature rise caused by burning.

However, when we are measuring compression, there isn't any burning. So, the temperature increase, whatever it is, must be considered.

If the heat caused by compression were drawn away as fast as it was created, the final temperature of the

gas would be the same as the beginning temperature. The resulting pressure would be the volume ratio, as stated above. This mode is called isothermal (constant temperature) and hardly ever happens.

At the other extreme, suppose none of the heat could escape. At the end, the gas would be both at reduced volume and increased temperature. Since both cause an increase in pressure, the final pressure would be higher than the isothermal case above. This mode is called adiabatic, and also hardly ever happens, because some of the heat escapes but some remains.

A comparison of these two ways of compressing a gas shows that the pressure rises more under the adiabatic condition, where the heat stays in the gas.

Equations have been developed to show this:

ISOTHERMAL: $P_2 = P_1 (CR)$

ADIABATIC: $P_2 = P_1 (CR)^{\gamma}$

The exponent, γ (gamma), is actually present in each of the above equations, but in the isothermal case its value is one, so it is not shown. In the adiabatic case, if air is being compressed, the value of gamma is approximately 1.4.

When gamma is larger than one, it has the effect of increasing the value of the term. If gamma were 2, for example, the CR would be squared.

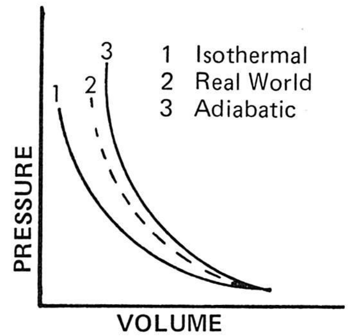
At a CR of 9, assuming all the heat stays in the gas, the final pressure will be about 23 times atmospheric, rather than nine times.

In the real world, operation will be somewhere between isothermal and adiabatic. Gamma will be some value between 1.4 and 1.0.

Since the shop manual tells us the pressure to expect, on one engine, we can work backwards and figure gamma for this case. It turns out to be about 1.2.

All of this is not very important to you, when your engine is running, because the heat from combustion is very much more than the heat from compression.

However, when you are measuring compression, knowing about gamma will prevent you from thinking that your super engine has even more compression than the manufacturer built into it.



Authors have rights, you know—It's very difficult to decide what to include in a book and how much to carry on about each subject. Basically, it is the author's "right" to put in whatever he thinks is interesting or useful. When it's all done, that is the only guide available.

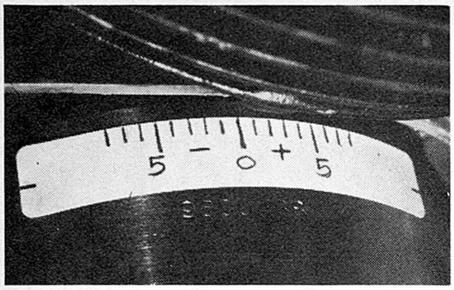
When I have read books on subjects in which I am very interested (such as motorcycles) I have usually wished the author had said more.

Reacting to that, I may have said too much in some places. If so, I ask your indulgence.

Readers have a corollary right too.

Which is to skip the dull parts, or not read the thing at all. However, I prefer not to think about it.

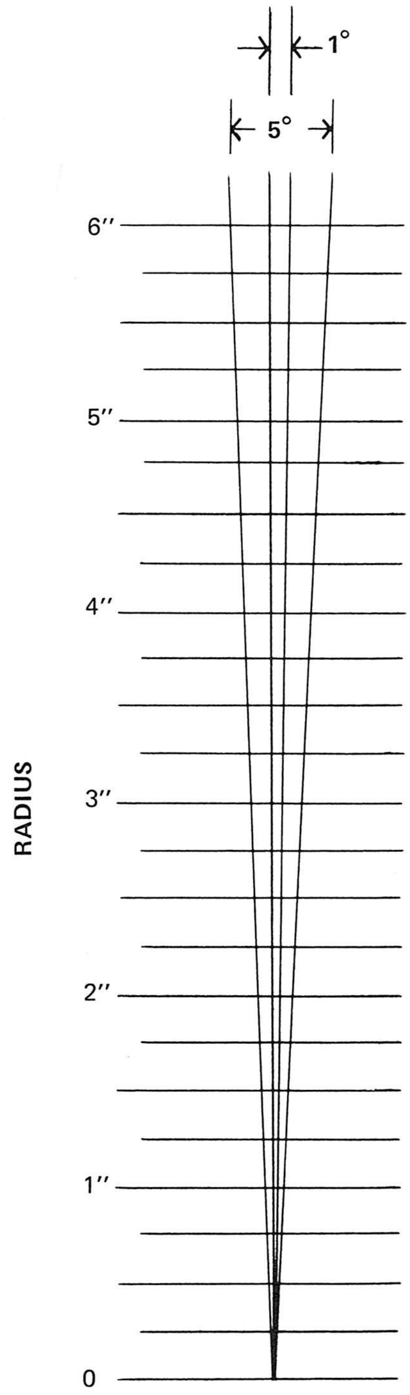
We'll be glad to hear from you! We cannot answer questions, diagnose, or give advice by mail. However, we will be delighted to receive your criticism, thoughts, or ideas. Which will help make books like this better.



When you are tuning, sometimes you want to know a degree-setting, and there are no degree marks on the engine. This chart provides spacing which will be reasonably accurate. To use, measure the radius of the flywheel (half the diameter) and draw a line across the chart at the proper radius. The distance between the two lines forming the inside angle will be one degree, at that radius. The distance between the two outside lines will be five degrees.

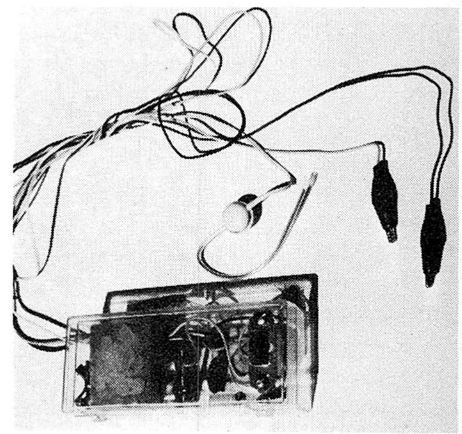
For small flywheels, it may be more convenient to use diameter, rather than radius, on the scale showing inches. If so, then the angles will be 2° and 10°.

For temporary use, these intervals can be marked off on a piece of tape and stuck to the flywheel. For permanent use, they can be scribed into the metal.



FLYWHEEL DEGREE CHART

Wayne Ebaugh of Albuquerque at last count owned five bikes. The handsome BMW shown, a 450 Husky, an Ossa Mick Andrews Replica trials bike, a Kawasaki, and a Penton. He mainly rides the first three and does well on all of them. Wayne is a capable mechanical engineer, an outspoken and effective advocate of the motorcycling sport, and a friend. He was kind enough to review the original manuscript of this book. For which, thanks.



Audio oscillator—A handy point-opening indicator, which can easily be put together by anyone familiar with electronic gadgets, is shown in this photo. It was assembled by the author in about an hour.

The ingredients are a transistor code-practice oscillator module, batteries, an on-off switch, and a transistor-radio-type earphone. All of which can be purchased at most retail electronics stores. This unit was assembled in a plastic box because the box was on hand.

The recipe is simply to wire the module up according to the instructions which come with it, except that the test leads are inserted into one of the wires going to the earphone. (A small loudspeaker can be used).

On a flywheel magneto, when the test leads are clipped across the points, this closes the circuit to the earphone, and the tone is heard. When the points open, the coils of the bike ignition are introduced into the circuit and the sound will change abruptly, both in tone and intensity.

It will sound like you are killing cats, but the opening of the points can readily and conveniently be observed. Also, dirty points can be detected because they make a scratching sound.

Miscellaneous notes—On flywheel magnetos, when checking point opening, be sure the key-switch, on the bike, is turned to "on." Otherwise, the switch shorts out the points.

On battery-ignitions, think about the presence of the vehicle battery before you connect anything to the points. Some indicators use the vehicle battery for power—a light bulb for example. Some indicators have a self-contained battery, in which case you want the vehicle ignition switch turned "off" so the two batteries don't fight each other.

With electronic ignitions, be wary of connecting anything which has a self-contained battery into the bike ignition system. The battery in the tester can possibly damage transistors in the ignition.

Also, with electronic ignitions, the low-voltage fed to the primary of the ignition coil can actually be 200 to 400 volts. If you have a tester hooked into that circuit, it can blow up the tester. Timing lights, on the spark-plug side of the ignition coil are normally OK.

Never kick over the engine, on a bike equipped with electronic ignition, unless there is a spark plug on the end of the plug wire and the shell of the plug is grounded to the engine case. When the metal shell of the plug is not grounded, the spark cannot jump the gap. In some ignitions, the voltage will simply continue rising until it makes a spark somewhere, usually inside the ignition. This damages the parts. This bit of advice can save you about ninety bucks!

The general rule, with ignitions, is the one stated—you rotate a stator for proper ignition timing. Some manufacturers, using flywheel magnetos, depend only on point-gap variations to set timing. An example is the "exploded view" of the ignition on page 73. Note that the screw holes in the stator plate are not elongated to allow rotation. This is normally satisfactory, however it does not allow the range of timing adjustment which is provided by a rotatable stator plate.

Motocross bikes require gearing to blast out of a tight turn and also to get wound out on the straight. This is why some small-displacement racers have six gears.
Bike is saving its fork seals from early death by use of Rap-On Fork Covers from The Dirt Rider Company, P. O. Box 26705, Tucson, Arizona 85726. Handsome rider is Tom Reddinger, manager of shipping for same company.

Gearing

Gearing has a major effect on the way a motorcycle makes use of available power. Stock gearing on a bike is not always suitable for the uses the owner makes of the machine.

Stock gearing is a series of compromises. Some are due to engineering considerations. Some are changes made to cause the bike to have greater appeal to some class of riders and thereby improve sales. If you don't belong to that special class of riders, then the "sales-department engineering" may not be right for you.

AVAILABLE POWER VERSUS REQUIRED POWER

The fundamental fact is this: In any gear the available power from the engine will rise with increased RPM to the power peak, and then go down with still higher RPM. As the speed of travel of the vehicle increases, the power required to maintain that speed also increases. At higher speeds, the dominant factor is wind resistance which increases as the square of speed. The maximum speed which can be obtained from a vehicle is at that RPM where the available power from the engine is the same as the required power to maintain road speed.

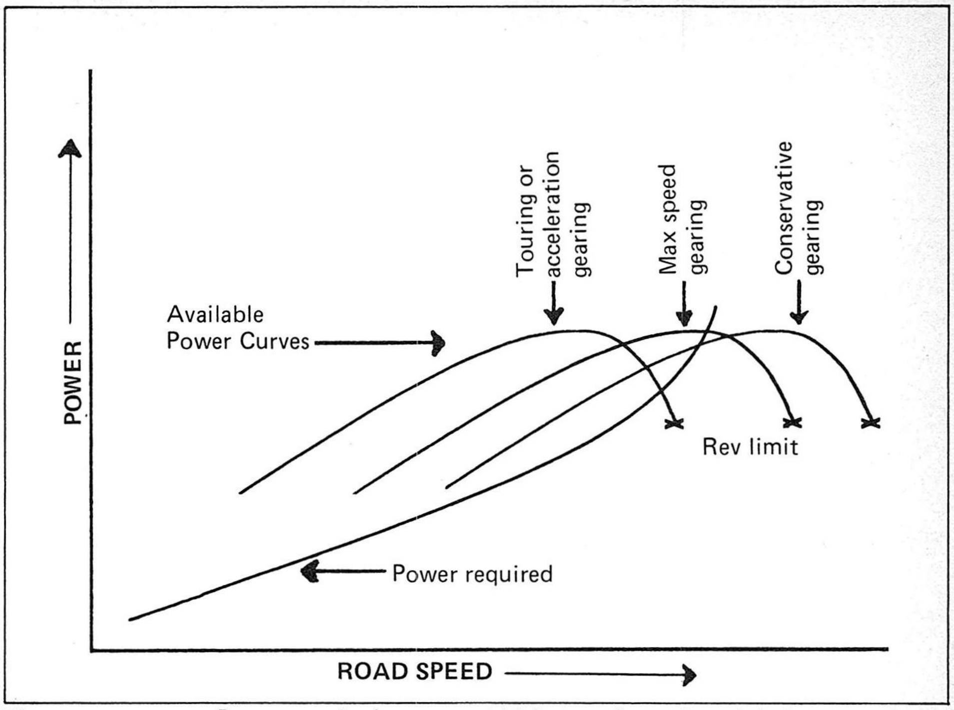
If available power and required power are plotted on the same chart, then the intersection of the two curves will determine the maximum speed of which the vehicle is capable.

The relationship between engine RPM and road speed is determined by the overall gearing. In order for these two curves to be drawn on the same chart, with road speed as the horizontal axis, some overall gear ratio is assumed.

A different gear ratio will cause the peak power point of the available power curve to shift to the right or to the left. Peak engine power (and all points on the available power curve) will occur at some different road speed, with different gearing.

This means that, by selecting gearing, the available power curve can be shifted, left or right, to meet the requirements of the designer or rider.

It would seem logical to arrange gearing so that the required power curve intersects the peak of



Three ways to gear. Power required goes up at higher road speeds mainly because of wind resistance. When required power curve passes through the peak of available power, that's as fast as the machine will go. If available power curve is shifted to left or right by gearing change, then bike cannot go as fast but may be better for some other purpose.

the available power curve. This would provide the highest road speed possible for that engine in that bike. Any other gearing will put the intersection of these curves at a lower power point and therefore a lower road speed.

All of the foregoing assumes that the bike is being operated on a level surface, with no wind.

SELECTING TOP GEAR

The measure of the ability of the motorcycle to accelerate, at any road speed, is the difference between the available power and the required power at that speed. If there is an excess of available power, and the rider chooses to use it, the machine can be accelerated to some higher speed.

On touring bikes with large engines and an abundance of power, the designer sometimes chooses to use gearing which moves the available power curve to the left. This reduces top speed to some lower value which is still probably over 100 MPH. It puts the power peak lower in the speed range and gives more acceleration at normal highway speeds, making the bike more pleasant to ride.

If a bike is geared like this and the rider actually wants maximum top speed, higher gearing (lower numerically) is indicated.

Since the RPM limit of the engine is normally higher than the RPM which produces maximum power, the gearing arrangement which puts the intersection of the two curves through the peak of the engine power curve will also prevent over-revving on a level road.

However, running downhill or with a tailwind has the effect of lowering the required power curve. Therefore gearing to allow maximum speed on a level road may allow serious over-revving on downgrades. If the designer wishes to protect his engine from the careless rider, he may deliberately change the gearing so that exceeding the rev limit, even on a downgrade, is hard to do. Such gearing puts the intersection of the curves to the left of the engine power peak.

By checking road-test data in magazines which do thorough tests (*Cycle World* is a good example) you can find data which will help you decide how a machine is geared. The road-test data will usually give the maximum power rating of the engine and the asso-

ciated RPM, along with the maximum speed that could be obtained and that RPM figure. This data will tell you where the curves intersect, for that bike.

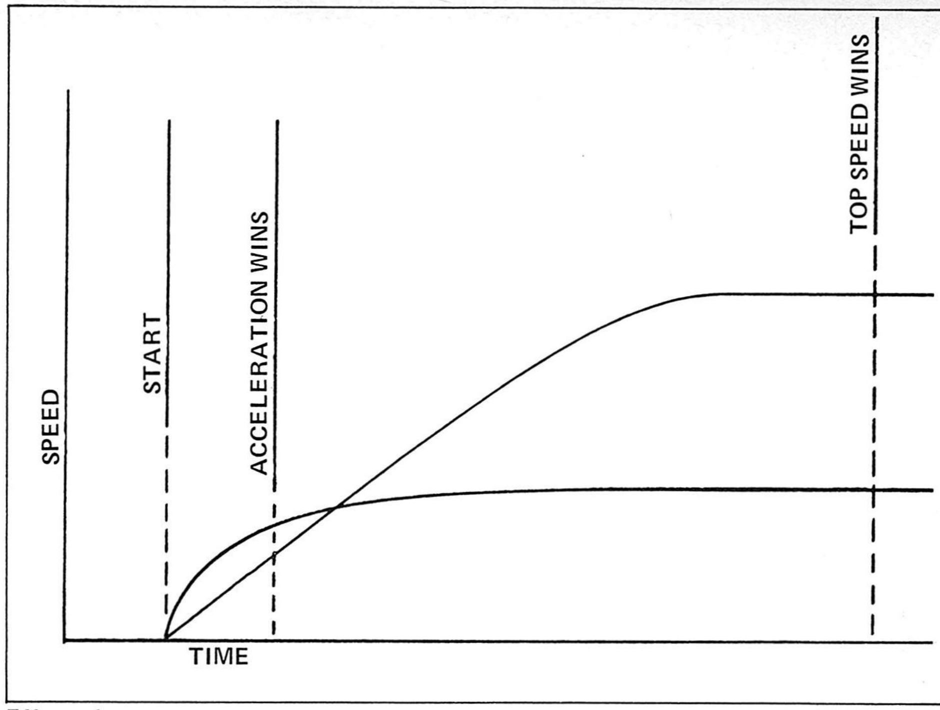
BOTTOM GEAR

After the designer has selected some top-gear ratio, he must choose a bottom ratio. This is done according to the type of bike. For a touring or trail machine, the low gear should provide easy starts from rest with minimum clutch slipping and engine revving. Also, the low gear should provide good hill-climbing ability. So, the numerical ratio will be high. On a race bike, a usable low gear at slow places on the course may be more important than easy starts, so the first-gear ratio may be numerically lower than for a road bike.

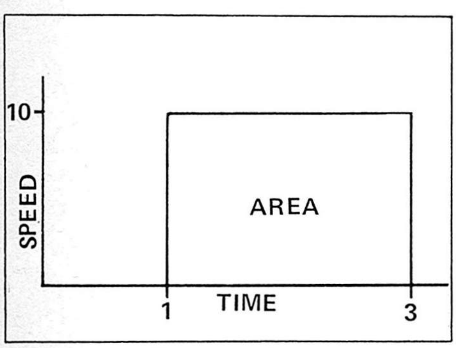
INTERMEDIATE GEARS

The spaces in between top and bottom must be filled with intermediate gears. The theoretical interval between gear ratios (as percentages) should be about the same as the interval between the RPM at peak torque and the RPM at peak power. On highly-tuned engines, this difference is such a small percentage that an impractically large number of gearsets would be required.

So, other compromises are made in spacing the gears. Sometimes the top gears are spaced close together and the lower gears have wide spacing, or the reverse.



Effect of gearing. In a short race, bike with most acceleration wins—top speed is unimportant. In a long race, bike geared for higher top speed will overtake and pass the bike geared for acceleration. Applying this simple idea to the complexities of a road circuit or an MX course is not so easy because the straights will be of varying length. However it's worth a little experimenting. Sometimes one tooth more or less on your countershaft sprocket can be a secret weapon.



This drawing illustrates the basic idea of the more complicated-looking chart above. If a vehicle starts at one o'clock and travels at a constant speed of 10 MPH until three o'clock, the distance traveled will be 20 miles. This is the same number as the area enclosed by the "curve." The base of the rectangle is 2 units, the height is 10 units. Area under a plot of speed versus time is equivalent to distance.

Without changing gears in the transmission or the primary drive, the best a rider can do is change the ratio between sprockets. This will change both acceleration and top speed in each gear.

ACCELERATION OR SPEED?

If a rider contemplates changing gearing to alter the behavior of the bike, a decision must be made (or found by testing) as to whether top speed or acceleration is more important. Most competitive events boil down to getting from A to B first, meaning in the least time.

The distance traveled is equal to speed multiplied by time. However, when the speed of travel is not constant, the computation of distance traveled requires either averaging the speed or use of complicated arithmetic. A graphical approach states the situation well.

If speed is plotted against time, and the curve is closed off at the ends by a starting line and a stopping line, then the figure formed will have some area. Since the area is the product of base times height, or in this case speed multiplied by time, the area under the curve is proportional to the distance traveled.

It is then possible to draw two curves, one showing high top speed but poor acceleration, and the other the reverse. Then, the best gearing can be selected by comparing the area under the two curves.

If time is relatively short, high acceleration is desired. If time is long, top speed becomes more important.

On a road course or motocross track, the problem is complicated by straights of varying lengths and entry onto the straights at different speeds. The analytical approach is complex, however it has been done on a computer. For the ordinary rider, best results are obtained by testing, using the "area-under-the-curve" idea as a guide.

Tuning Procedure

By now, hopefully, you understand all of the theory and practical things discussed earlier. You should know how to take your carburetor apart, identify the jets, and change them and the position of the needle.

You should know how to take plug readings to check engine temperature and get a clue as to F/A ratio. You should understand the effect of mixture and RPM variations on ignition timing. You should understand how your ignition works and how to adjust it.

You should have adopted some way to measure ignition timing, compression, and performance. You should have practiced performance measurement a little, so you get a better feel for the sensitivity of the measurement. You should know how to perform routine maintenance such as cleaning the air filter, getting the carbon out of the engine, replacing rings, and such, or be prepared to have these things done for you.

You should understand the effect of air density on power capability and tuning requirements, and you should be prepared to use RAD numbers as the landmarks in your tuning records.

ORDINARY TUNING

Many riders simply want to make their motorcycles run reasonably well and are not looking for that last few percent. The same principles and methods apply, as discussed in the preceding sections, however they do not need to be carried as far or practiced as diligently.

For these riders, let's start with a simple tuning procedure which will make a bike run well.

- **First, service the bike so it is in good operating condition. Air cleaner, plug gap, and controls set properly.**
- **Set ignition timing to spec.**
- **Make a full-throttle spark-plug reading and adjust the main-jet size for a light tan color on the insulator. Be sure the plug you are using is a recommended heat rating.**
- **Make a half-throttle plug reading and move the needle up or down to get the light tan color on the plug. If necessary, change the needle or needle jet as required.**
- **Set the idle adjustments according to the owner's manual.**

Unless there is something mechanically wrong, such as poor compression, defective ignition parts, worn-out carburetor slide or air leaks somewhere, the bike should run quite well after you have done this.

TEMP. °F.	SATURATION PRESSURE (" Hg)	SATURATION % H_2O
0°	0.038"	0.12%
20	0.103	0.33
40	0.247	0.83
60	0.521	1.7
70	0.739	2.5
80	1.03	3.3
90	1.42	4.7
100	1.93	6.5

Effect of humidity on power—Humidity has an indirect effect on engine power. The effect is small except when both relative humidity and temperature are high.

Water vapor is a gas. When gases are mixed together, and do not react chemically, then each exerts a part of the total pressure of the mixed volume of gases.

If water is available to evaporate into the atmosphere, it will evaporate until it reaches its saturation pressure, which is a function of temperature, as shown on the table.

At 100°F. the saturation pressure of water vapor is about 2 inches of mercury. If the barometric pressure at the time is 30 inches, then the pressure of the air is only 28 inches, a drop of about 6% due to water vapor being present.

The density of that part of the *atmosphere* which is *air* will be less by 6%, and the engine power capability will be similarly reduced. The F/A ratio will tend to be rich.

Usually the amount of water vapor in the air is less than the saturation pressure. This is expressed by relative humidity which compares the amount of water vapor present to the saturation value.

To find the actual amount of water vapor in the air on a particular day, refer to the data table and find the Saturation % H_2O for the temperature. Multiply this percentage by the relative humidity at the time, and the result will be the partial pressure of water vapor in the atmosphere. The pressure of the component of atmosphere which is air will be reduced by that amount.

To extend the correction to RAD, reduce the RAD number by the same percentage. Suppose RAD, as shown by the chart is 90. The temperature is 80° and the relative humidity is 60%. From the table, the saturation percentage is 3.3%. 60% of 3.3% is very nearly 2%. The RAD of 90, reduced by 2%, would be 1.8 smaller, and we would round off to 88.

You can get to the same answer with these formulas:

Corrected RAD = (RAD from curve) x (100 – Factor)

Factor = (Saturation % H_2O) x (Relative Humidity)

TUNING FOR PERFORMANCE

With a bike that is running reasonably well, you can then start tuning for performance. This is the fun part and is something like a chess game. *Records are vital.*

The first thing to do is establish what the level of performance actually is. You do this by measuring performance however you choose, possibly with a stopwatch. Write down the results.

Blank forms are provided in the back of this book which should be useful to you in keeping records. An example of tuning with these forms is in the following section.

After initial performance measurements are taken and recorded, you record all of the data which provided the performance level just measured. This includes RAD, carburetor jets and settings, ignition setting, engine-compression reading, spark-plug type, and anything else you may consider relevant or worth remembering.

All of this may take half a day, but it gets you a starting point. Now, you can start looking for improvements.

If the engine is running fairly well, you can assume that the mixture is within reason and start with ignition timing.

Vary the ignition timing and measure performance at both full throttle and half throttle. Record the results. While measuring performance, take plug readings at the end of each test and be constantly alert to detonation. When you find the timing that gives best performance without heating or detonation, record it and circle the number. You will use that timing unless you later find some reason to change it.

If the temperature is changing a large amount while you are tuning, it causes a problem in interpreting results. Each change in temperature of 5 degrees changes power capability about one percent. When the temperature has changed 10 or 15 degrees, it will start to fuzz up your results, so it may be better to stop tuning until the next day, or the next time the temperature comes back to the value at which you were tuning. It pays, also, to keep an eye on barometric pressure, however unless a weather front is moving past, it will not change very much in a few hours. What you are after is spot-on tuning for one particular RAD number.

After timing is set, vary the main jet, with accompanying performance checks and plug readings to see where you are on the fishhook curve. Make the first jet change in the rich direction, and go from there. Some bikes will show significant change with one jet size change, others may require two steps to produce a large change, depending on the design of the engine. Choose the value which gives best performance at full throttle and record the value, drawing a circle around the number.

Repeat the process with needle-position changes and performance checks at both full throttle and half throttle. The needle position will have an influence on full-throttle performance. If you were unable to decide between two main jets in earlier testing, a change in needle position may make it clear which to use. If so, change the jet and resume testing.

Unless you made a drastic change in main-jet size, the ignition timing chosen at the beginning should be OK and you probably will not find significant improvement through retesting.

There is normally no need to change the idle jet unless it is the stock jet and the bike is being operated at 5,000 feet or higher.

If acceleration is poor from stop, the idle jet changed for richer mixture may correct it. Otherwise a change in throttle-slide cutaway is indicated.

Measurement of engine compression gives you an idea how far the engine is from new condition or from an overhaul. If compression is down about 15 psi, it is costing you about five percent in power and no tuning adjustment will restore it.

When you optimize each tuning variable, you have tuned the engine to run as well as it can for that particular RAD and for the engine conditions at that time. You have also set up a baseline.

THE BASELINE

All of the final data from your tune should be summarized on one line, along with the RAD value for which that tuning is valid.

From there, performance will change due to engine wear and due to changes in RAD.

When you are operating at RAD numbers significantly different than your baseline RAD, you may wish to retune and find different engine settings. If so, you have set up another baseline for the different RAD. The amount of change in RAD which you will consider to be significant is, of course, up to you.

IT GETS EASIER!

After you have tuned to several different RAD values, you can start tuning from your data without relying so much on testing. You can interpolate between baselines and choose settings for RAD values that you have never tuned to. Whenever RAD numbers repeat, you can repeat previous settings and make one quick check against baseline performance.

HOW OFTEN?

The attention you pay to all this depends entirely on the level of performance you want to maintain, the responsiveness of your engine to the tuning variables, how much you enjoy tuning, and how well you manage to do it.

If you tolerate deterioration until performance becomes noticeably poor, and then just want to make it run better, the ordinary tuning described at the beginning of this section is probably good enough.

If you find that you enjoy riding more when the bike is in good shape, you may tune once for cool weather and again for hot weather, using two baselines.

If you are a competitor, at different altitudes and temperatures, and you like to run well, you undoubtedly tune for each race. In this case, RAD numbers and records are invaluable and there is no real substitute.

When you travel to a race, there is usually neither time nor opportunity to tune from scratch. With RAD baselines, you can tune to most conditions in an hour and be confident of your settings.

The payoff, after you get into the system, is both easier tuning and better tuning. All of your past experience is condensed into your records and helps you every time you tune. The payoff is also some percentage of improved performance over other bikes which are not so well adjusted.

WHAT TO WATCH OUT FOR

When you start looking for best performance, changing settings, and testing, you run the risk of engine damage. The risk is small if you proceed carefully and intelligently.

You may be tempted to use somebody else's settings, or a spark plug that is recommended, because you have some assurance that they work. *You have no assurance that they will work on your bike.*

In my opinion, it is far safer to proceed on your own, following these procedures, than it is to blindly accept truth which often turns out to be unfounded rumor.

Here are some things that can happen:

Too rich—No problem. The plug should foul.

Too lean—Excessive heating. If you are taking plug readings, you should see it in time to prevent damage.

Plug too cold—No problem. The plug should foul.

Plug too hot—If you leave it in, preignition may result. If you take readings, you will see that it is too hot.

Ignition retarded—Excessive heat. Plug readings and performance will tell you.

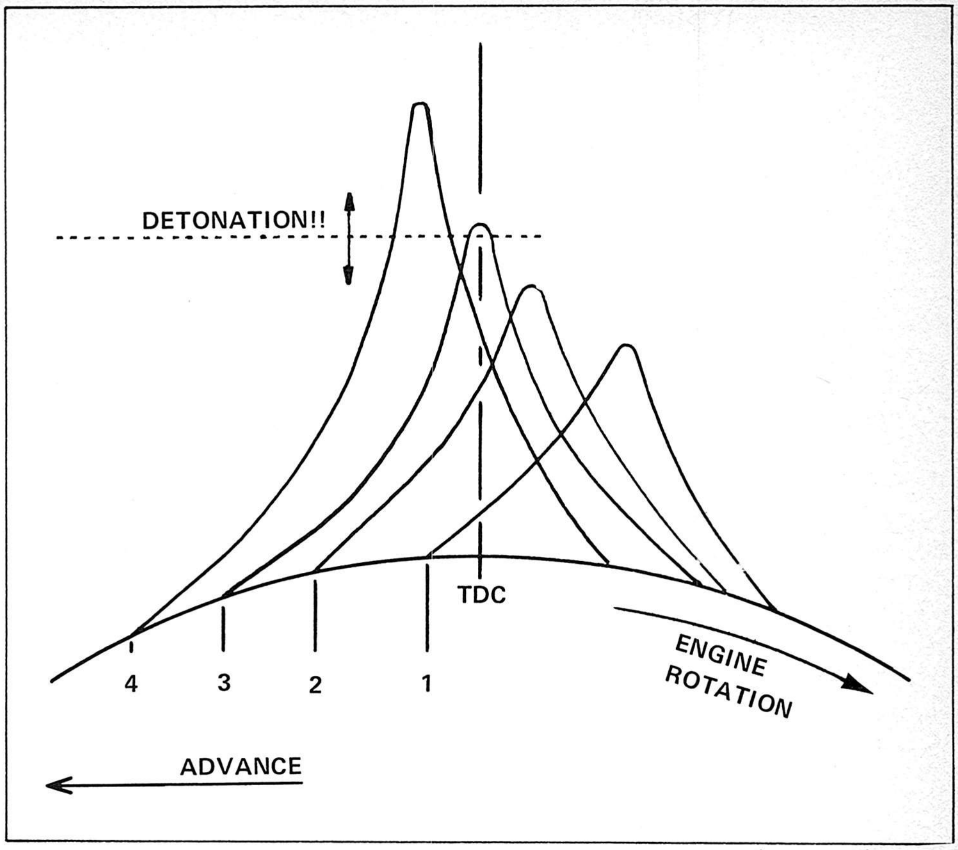
Ignition advanced—Detonation. If you don't hear it, it will cause damage. Often a full-throttle plug reading will show heat on a plug of the heat range which has worked well in the past.

Notice—The information and procedures contained in this book are believed to be valid.

Engine damage can result from improper tuning or adjustment. Since the application of data in this book is not within the control of author or publisher, liability for use of this information is disclaimed.

When you venture to tune or adjust your engine, particularly in the search for better performance, there is always the risk of having something go wrong.

Thousands of people tune their own machines successfully and enjoy the result. Some wind up breaking their toys.



This drawing is to remind us. It shows pressure buildup due to combustion added to the pressure due to mechanical compression.

Timing at point 1 is too far retarded. Heating and reduced power will result.

Timing at point 2 is better, and normal for many engines.

Timing at point 3 is still better, however the peak pressure is at the threshold of detonation. With a slightly richer mixture or better cooling, an engine might live with this setting.

Timing at point 4 is intolerable. It exceeds the detonation level and also produces peak cylinder pressure before TDC. Even though peak pressure is higher, power will be less because this pressure is trying to make the engine run backwards.

The trick is to find the timing between points 2 and 3 which works best for your engine. This will vary with RAD and, to some degree, with outside temperature.

The detonation level is not fixed, but can move up or down with different fuel, RAD, temperature, engine compression, and timing. It's a chess game, and the best players win.

An Example

Here is an account of the actual tuning of a particular bike. It is a 125cc Penton, in average condition. The bike is used for motocross and play-racing. When raced, it has been running around third or fourth in the expert class.

At the time of tuning, the bike was essentially set up as delivered by the dealer, with his standard settings for this area. The machine can be considered to be in a condition of *ordinary tune*, as described earlier. It had never been individually *tuned for performance.* It had electronic ignition, added on after purchase, so the timing could not have changed from original setting.

The fact that the bike had been fairly competitive in its class is evidence that the standard settings were pretty good. The fact that the bike was rarely first suggested that the standard settings could be improved. This, of course, is something the owner should do, in order to find the optimum tuning for his particular bike.

A remote location was selected so as not to annoy the population with the test runs. This is important!

Markers were established on an uphill section so that the gradient would tend to hold down the engine RPM at top speed and also load the engine properly. The test runs were started far enough back from the markers that the engine was at top speed when the measuring section was entered.

A few test runs were made, to stabilize the riding and timing procedures, and hand signals were developed between rider and timer.

At this location, full-throttle runs in fifth gear produced running times of around three seconds, which is rather short. The stopwatch used measured to 0.1 second, which is about 3% of the total running time. A longer time of measurement would have been better—perhaps ten seconds—however the location did not allow that.

Incidentally, this was the first time we had used this road for testing. It was newly paved, and no houses were near it, so it was ideal, except for length. As you will see, results were satisfactory with only a three-second timing interval, except that a final adjustment was made after running the bike for a longer period of time on a nearby dirt road.

All times recorded were an average of at least three individual runs under the same conditions. The readings were remarkably uniform which implies precision of measurement.

In the following account, the paragraph numbers correspond to the numbered lines on the Tuning Record Form, which is a copy of the one used on the day of tuning.

1. RAD was determined from temperature with pressure, and recorded. Initial performance measurements were made at full and half throttle and the data entered on the first line.
2. The ignition was opened up and a scale was taped on the stator plate to provide a reference for timing adjustments. The scale markings were arbitrary. Original timing was zero on this scale. Timing was retarded to −2 on the scale, and the performance checked. The machine was about 3% slower at full throttle and about 10% slower at half throttle. Not the way to go.
3. Ignition timing was changed to +2 and tests repeated. Full-throttle performance went up 12% and mid-throttle performance improved by 15%, compared to the original measurements. Plug readings were still OK at this setting. Since the amount of advance was large, we decided to hold that setting and check mixture.

The percentages—What can a small percentage do for you? If you compete, it can do a lot.

At recent motocross races, riders in nine expert heats were clocked. The time difference between the finish of the winner and the finish of the second-place rider was an average of 1.3% of the total riding time in the heat. These riders raced for about twelve minutes and, at the end, the winner averaged a ten-second lead. The distance looks like more than that but the timeclock tells the story.

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4. Main jet was reduced from no. 135 to no. 130, all other settings remaining the same. Speed went down 4% and 9%, compared to the previous reading. Also, the plug showed evidence of heating. The reason we went to a leaner main jet for the first test, rather than richer, is that the dealer had advised that he was now delivering that model with a no. 130 main jet. It turned out that he was right, but at this stage of testing it looked lean.
5. A no. 140 main jet was tried and performance was worse than with the no. 135. The engine sounded rich, running through the trap, and seemed on the verge of fourstroking.
6. The no. 135 main jet was put back in and the test repeated. Running times were the same as with the no. 135 jet used the first time, on line 3.
7. The needle clip had been in the top groove, which we considered to be groove no. 1. It was changed to groove no. 2, making the mixture more rich, and tests were run again. Performance at both full and mid-throttle was better than any previous test.
8. The clip was moved to groove no. 3 and performance fell off drastically.
9. The clip was put back into groove no. 2, tests repeated, and the best readings repeated again. The best settings for all variables were recorded on this line and regarded as a temporary baseline.
10. Because the test interval was very short, we reasoned that engine temperatures had not stabilized during the speed runs, even though some warmup was allowed before each set of runs. The bike was then ridden hard, on a nearby dirt road, uphill for about a mile. It was also tested on some steep hills. Several plug checks were made during this phase to guard against overheating. The result was a feeling, on the part of two riders, that the engine was rich at full throttle and maximum RPM. As a result of these longer-duration riding tests, the main jet was changed down to the no. 130.

Retesting on the measured course showed no loss of speed from the previous best readings, and the plug still looked OK.

The probable reason for the no. 130 jet being good the second time we tried it was that the needle position had been changed in the interim to a richer setting. This has an effect both at half throttle and at full throttle.

	temp 75°		press 24.2"		TUNING RECORD				date 9/10/72		place ABQ
	RAD	MAIN JET	NEEDLE POSITION	IDLE JET	IGNITION TIMING	COM-PRESSION	PLUG	PLUG READING	PERFORMANCE FULL	PERFORMANCE HALF	NOTES
1	78	135	Top	45	0	105	2H	OK	2.9 Sec	3.5	Initial Run
2					-2			OK	3.0	3.8	drop 3% + 10%
3					+2			OK	2.5	3.0	Up 12% + 15%
4		130						HOT	2.6	3.3	
5		140						OK	2.6	3.1	Sounds Rich
6		135						OK	2.5	3.0	
7			#2					OK	2.3	2.8	Plug Read ½ Throttle
8		135	#3					OK	2.5	3.8	
9		135	#2		+2			OK	2.3	2.8	Rich on Road Test
10	78	130	#2	45	+2	105	2H	OK	2.3	2.8	BASELINE

If, after selecting the new needle position, we had retested for main-jet size, we probably would have changed to the no. 130 then, rather than after road testing.

Temperature at the start was 72° and at the finish it was 79°. We considered it to be 75° on the average. Altitude was about 6,000 feet and the barometric pressure, according to the weather report, was about 0.2 inches above normal. Reading the RAD chart with these values gave a RAD number of 78 for the baseline data.

Bikes, as delivered from the factory, are supposed to be set up for operation at around RAD number 100. If a bike is operated nearer sea level than the example reported above, it may not respond as much to tuning variations. However there is one best setting for every RAD and the only way to find it is by trying and testing.

A little more than half of the improvement found with this particular bike resulted from ignition timing—the rest from carburetion.

The time spent in tuning and testing, doing all the things shown on the record form, was about four hours. The cost was 80¢ for the new jet. The payoff, in this case, was a 20% improvement in performance both at full throttle and at half throttle.

It's A Pleasure To Say Thanks!

Fine companies and individuals exhibited interest in you, the reader, by helping me do a better job.

Carl Hailey of American Honda Motor Company provided the drawings used to illustrate the discussion of the constant velocity carburetor, and others used in the book.

Brian Newberry of Nortin Villiers Corporation furnished data and tuning info from their shop manual on the AJS motorcycle.

Ivan Wagar, editor of Cycle World magazine, kindly allowed use of material from an article by the author of this book, which first appeared in *Cycle World.* This material was the basis for the discussion of gearing.

U. S. Suzuki Motor Corporation furnished copies of their excellent training publications on carburetion and ignition. The drawings used to illustrate the different types of air-bleeds came from these publications.

Chuck Crawford of Kawasaki Motors Corporation contributed data and drawings on electronic ignitions, along with the performance curves on the spectacular Kawasaki 750.

John Sempter of K & D Accessories Company furnished information on the use of their air density meter.

Jeff Robinson of Clymer Publications furnished copies of the entire series of Clymer Repair Manuals, which were very useful references during the preparation of this book.

Geoff Binks of AMAL Limited assisted greatly in providing data on AMAL carburetors.

Marvin Foster of Pabatco, designers and importers of Hodaka motorcycles, unloaded his data files on us and provided much that was useful. Many of the carburetor drawings and data are taken from Hodaka literature.

Bill Fisher of H. P. Books allowed use of their publications for reference. Their books on *Holley Carburetors* and *Turbochargers* provided interesting comparative data.

R. H. Kilburn of Central Tool Company furnished tune-up items from their line of precision measuring equipment, including the dial-indicator used to measure piston position.

Tracy Holmes of Patraco kindly provided tech data on their dynos and diagnostic equipment.

C. Robert Smith of Champion Spark Plug Company furnished data and illustrations on spark plug "reading" and heat ratings.

Jerry Kono of Sudco International was very helpful in providing data on Mikuni carburetors.

Jerry Ballard, while with *Popular Cycling* magazine, dug into their files for some of the photos used. He's now with *Motorcycle Industry*.

Some of the data used here has been published in articles by the author for *Dirt Bike* magazine.

Frank D. Record of Record Importing and Distributing Company furnished "direct-from-the-factory" tech data on Mikuni carburetors and pointed out some of the differences between "standard" and "road-racing" Mikunis.

Wayne Ebaugh of Albuquerque contributed the photos and descriptions of modifications he performed to his Husqvarna.

Paul Olmstead and **Jim Foushee of Powroll Performance Products Inc.** gave us a look at their high-performance parts for Honda four-strokes and discussed their hop-up philosophy and guidelines.

Racer Brown of Racer Brown Camshafts, Inc. allowed use of his authoritative and entertaining monologue on camshafts taken from the camshaft chapter of H. P. Books' *How To Modify Datsun Engines & Chassis: 510, 610 & 240Z.*

This is an independent publication—What it says, and how it says it, is the responsibility of the author. Assistance received from these firms does not imply endorsement or agreement with the content of this book.

Information and technical data about these manufacturers' products—was graciously provided, along with permission to use many of the sketches and illustrations. In order to fit the factory drawings into the format of this book, they were used where they would do the best job, and some have therefore lost their identity, in terms of source.

However, we want you to know who helped.

Modifying Your Engine For Better Performance

The theory and practice of tuning, as discussed so far, is applicable to most engines, stock or modified. We have covered the tuning adjustments which make an engine run properly and which if carefully done will extract maximum performance.

Some riders want more than best performance out of a stock engine and undertake various kinds of modifications to achieve this. In some cases, these engine mods are a trade-off. What you gain in one aspect of operation you lose in another. Typically, things which improve peak power will tend to cause that power peak to happen over a narrow band of RPM at a higher engine speed and will also reduce the available power and torque at lower speeds. This is not always the case and there are some things you can do which will improve performance *without any penalty.*

MAKING IT STOCK

One improvement without penalty is simply making it stock.

A friend of mine does engine and chassis mods as a business. People bring their bikes to him, tell him what they want to do better, and he makes appropriate modifications to the machine. Because engine hop-up procedures are often described in the magazines, lots of these customers come into the shop with some pretty definite ideas about what they want done. A thing they often overlook is that the first step is to make it stock and this is sometimes all the improvement needed. If the rider doesn't plan to race the bike, use it in hillclimbs, or do anything unusual with it, the performance he is after may be already designed into the engine but not available because of variations in the manufacture and assembly of that particular engine.

It isn't very dramatic to pay money and go into a big mod program with the goal of making it stock. My friend doesn't have much success selling just that even when he is pretty sure that's what the customer really wants to buy.

It goes over better if it is given a fancier name. *Blueprinting.* Most everybody has read or heard about bikes or cars which have been "blueprinted" and therefore run faster than scoot. Of course, blueprinting only means to make the thing just like the manufacturing drawings say it should have been made—in other words, *stock.*

There are some examples of things to do to blueprint your engine later, along with some pictures. To give you the general idea, if you look into the air passage between the carb and the engine you may see some misalignment of flanges and resulting restrictions to air flow. Obviously the designer didn't intend it to be that way. The usual cure for things like that is simply to use a high-speed hand grinder and match up the ports with smooth contours. This will make the engine run better at all RPM, give it better torque and consequently better power—but not more power than the blueprints provided for.

CHANGING THE DESIGN

After you have made the engine stock, then you may wish to alter the engine design to make it do something different than the designer intended.

There are two important things to think about. The first is that it makes no sense to modify an engine until you have first blueprinted it. You can of course do the blueprinting while you are also doing the mods. But don't think you can find satisfaction from high-priced custom parts installed in a sick engine. The guy I am after in this paragraph is the one who puts a trick camshaft in an engine which needs rings.

The second thing to remember is that when you are changing the design, you are changing the design. What you are going to wind up with is not what the factory built and not what the designer put on the drawings. Expect surprises.

For example, I have an engine in my garage right now in which the top of the piston bangs on the head. I sometimes mill the head to increase compression because I live about a mile above sea level. I am not trying to hop up the engine by doing this, I am just trying to get the compression pressure up to what it would be if I were operating the bike at sea level.

This sick engine is brand new and is a make I have used before. I did the same thing to this engine that I did to another one just like it, and it worked OK before. On this one, the manufacturing tolerances evidently stacked up the wrong way and when I took my standard cut off the head it turned out to be too much. The fix is more machine work to provide piston clearance space in the head. Obviously, if I had not changed the design, I would not have this problem.

Some people regard engine mods as a contest of smartness between themselves and the engine designers. Somehow, the engine modifier always wins this contest and then goes around telling people how dumb the factory was. He may have installed a giant carb and, sure enough, it goes faster at full throttle and high RPM. The designer knew about that.

What the modifier will not tell you is that, at low RPM, it will not run at all. The designer knew about that too.

In a few cases you may actually have to repair some serious design error, but not often. In general, you should acknowledge that the factory built a reasonable engine for the job it is intended to do. If you want it to do some other job, then you will probably benefit from changing the design. If you do it right.

HOW ENGINES WORK, SORT OF

It is always mildly astonishing to me when I see somebody industriously starting to change the design of an engine and then discover that he doesn't know how the engine works. You can succeed at this if you are using the "cookbook" method. You buy a kit of parts and some well-written instructions for those exact parts in your exact engine. Then if you follow the recipe exactly, it *should* work.

It is better to have a pretty good idea of how the engine works before you start changing the design for a couple of reasons. The recipe books which tell you what to do usually assume you know a little bit about the engine and they tend to leave out simple, but vital, information.

Also some mods, particularly to two-strokes, are done to the existing parts by

removing metal. If you don't know what the changes are doing to the functions of the engine you can get into big trouble. The old saying, "If a little is good, a lot is better," is positively not true when you are grinding on the gizzard of a two-stroker.

Very often a motorcycle is a young man's first encounter with an engine that he is allowed to tinker with. If he has heard about engines in school or read about them in the popular literature, he has gotten some oversimplified versions of how they work. Unfortunately, the ideas which are left out of the simple explanations are exactly those needed to understand what you are doing when you are modifying for performance.

The things we will consider here are mainly those which are left out of simple explanations—plus a couple of other ideas which I have tossed in just because I think they are interesting. After this discussion of engines, we will talk some about modifications.

THE TWO-STROKE ENGINE

If school books and teachings even bother to mention the two-stroke, it is as an oddity and most of the emphasis is, "Gee Whiz, look at all the things that happen while the piston goes up and down!"

Even though a two-stroke is mechanically more simple than a four-stroke, it is intrinsically more complicated, precisely because of all the things that happen while the piston does that. So we start with the two-stroker.

These goings-on can be understood by anybody, at least in concept. Although it is mainly conceptual understanding that we are after, there will be some landmark numbers here and there for reference and comfort.

You have probably read about two-strokes before and are now apprehensive that I am going to elaborate some more about the piston doing that. I am only going to do it once. This will later force me into some trickery and evasions so as not to do it again and, if you watch closely, you will catch me at it.

FOUR STROKES PER PARTICLE

If you imagine a particle of air, painted red so we can see it, at the entrance to the carburetor, then you can see that in the "two-stroke-cycle" there will be four strokes of the piston before that particle of air pops out into the exhaust pipe. A stroke, of course, is a movement of the piston from top to bottom or vice versa.

If the piston is at the bottom to begin, as it moves up it creates reduced pressure beneath it, inducing air and fuel to flow into the crankcase. When it moves down again, it will compress the mixture in the crankcase and then cause it to flow upwards, through transfer passages, into the space above the piston. For this to happen the intake passage from the carburetor, and the transfer passages, have to be opened and closed at the proper times. In the simplest and most common form of two-stroke used on bikes, this opening and closing is done by the piston.

On the next upstroke, the mixture above the piston is compressed and ignited near the top of the stroke. Combustion pressure then drives the piston back down again, during which power is extracted. As the piston nears the bottom of its travel, it uncovers the exhaust port and the burned gases exit, including our red-colored particle. For this particle, two revolutions of the crankshaft were required to induct, burn, and expel the particle—the same as in a four-stroke engine. How about that, two-stroke fans!

The requisites for an internal combustion engine are: Induction, Compression, Expansion, and Exhaust. The four-stroke does these things simply and serially, using only the top side of the piston, and thus requires four strokes to get it all done.

The two-stroke produces a power stroke every revolution by doing two different things at the same time, making use of both the top and the bottom of the piston.

An analogy is two circus parades arriving at a junction in the road where they merge together. Each parade is basically a simple array of events. When merged together, it looks more complex, and the observer sees twice as many elephants and fat ladies.

Figure 1A is a sketch of a simple piston-controlled two-stroke. The inlet is opened and closed by the bottom edge of the piston. The transfer and exhaust ports are controlled by the top edge of the piston. Figure 1B is a scary-looking timing diagram for this engine.

EVENT SEQUENCE AND TIMING

An important point, which you can gather from either part of Figure 1, is that port timing is symmetrical in a piston-controlled engine, which is not a good thing. Symmetry means that if the piston opens a port and then travels two inches up to TDC, the port will be closed again when the piston has come back down two inches from TDC. Which boils down finally to the big news that the ports in the side of the cylinder didn't move any.

Port timing for a particular engine can be specified, if you choose, by stating the port location. It can also be stated in degrees, as indicated by the timing diagram of Figure 1.

This diagram, based on clockwise rotation, shows the order of events and their "timing" in degrees of crankshaft rotation. Conventionally, the pole-stars for reference are TDC and BDC, and event timing is referenced to one or the other according to which is appropriate. Intake is centered about TDC and therefore generally stated as degrees before and after TDC. The other two events, exhaust and transfer, occur physically while the piston is traversing BDC and are commonly referenced to that pole.

A set of numbers from a recent Suzuki twin is in the table below and also on the timing diagram.

	Timing	Duration
Intake	66° BTDC to 66° ATDC	132°
Exhaust	84° BBDC to 84° ABDC	168°
Transfer	58° BBDC to 58° ABDC	116°

Because these numbers use different references, they tend to obscure an important point, so let's convert the intake timing also to degrees away from BDC. The number (180 - 66 = 114°) is on the diagram with an arrow showing it is measured from BDC.

Now we can wrestle with these numbers a little. We can assume that compression in the crankcase cannot occur when a port is open, so the duration of the crankcase compression event is 114° BBDC to 58° BBDC, a span of 56°, at the end of which the transfer ports are opened and the mixture is squirted upstairs.

At 58° past BDC, the transfers close and the intake is not opened up yet, so a vacuum or reduced pressure is created in the crankcase.

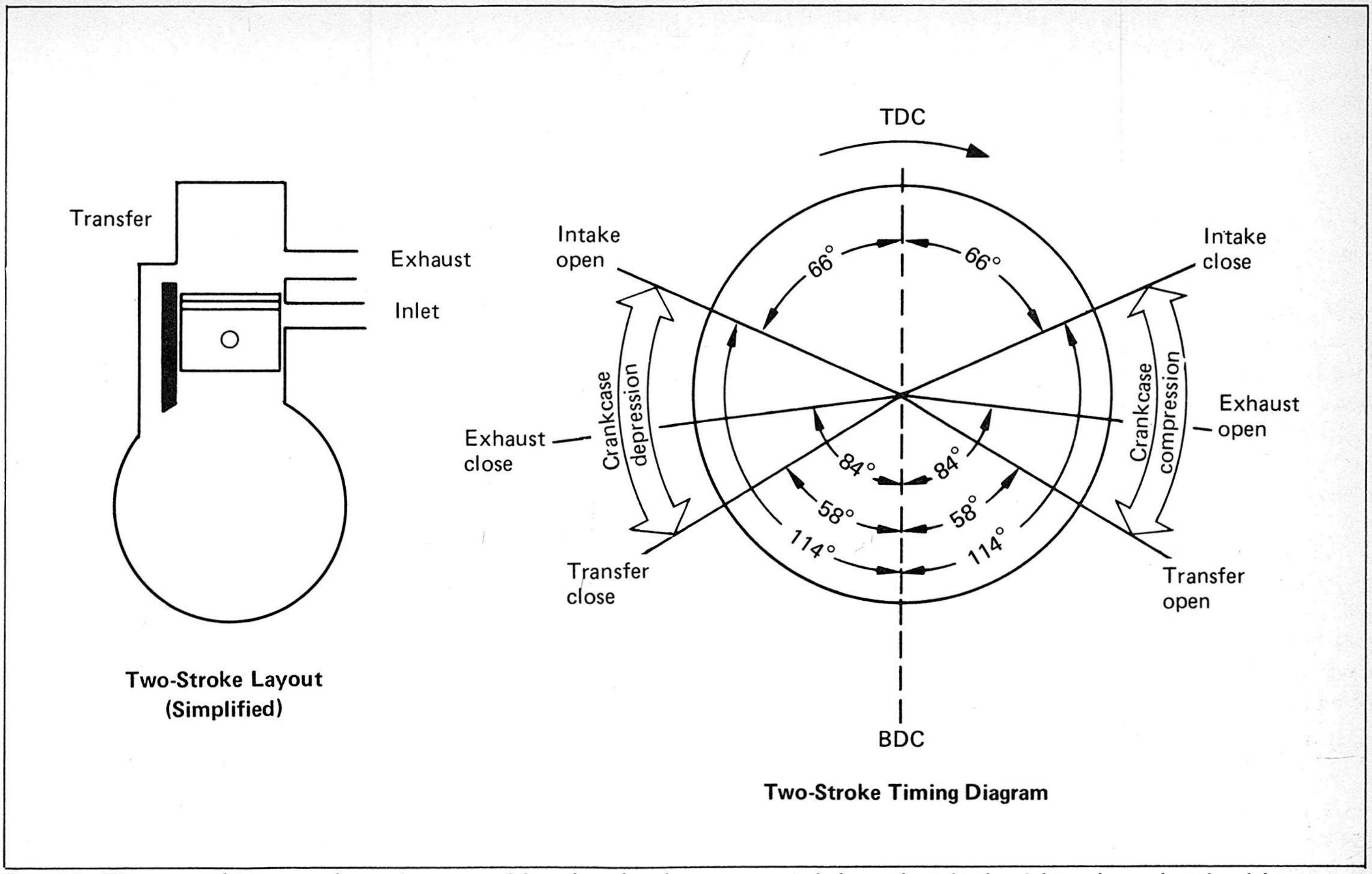


Figure 1—The ports of a two-stroke engine are positioned so the piston opens and closes them in the right order and at the right times. Simplified diagram of the engine shows the scheme. The timing diagram shows actual event timing (in degrees) of a Suzuki twin.

The interval allowed for this crankcase *depression* is also 56°, due to symmetry. At the end of this period the intake opens and new mixture rushes into the case.

One of the mods performed to two-strokes in the search for higher peak power is to make the piston shorter, on the side where the intake port is located. This is done by cutting off part of the piston skirt. This will change intake timing. If we agree that the inlet is open as soon as the bottom of the piston clears the bottom of the port, then we can see that the piston will have to travel a shorter distance away from BDC to start opening the inlet. When it opens earlier, it also closes later, due to symmetry, and this gets us into some problems. Any *increase* in intake duration causes an equal *decrease* in the interval allowed for both crankcase compression and depression.

EXHAUSTING

If you aren't yet, let's look at some of the things happening above the piston, with reference to the timing diagram.

The poorest marcher in the parade is the exhaust. It needs a pull from the front and a push from the rear to keep up. It gets this help from a tuned exhaust pipe and from the ingress of fresh mixture which tends to crowd the exhaust out of the cylinder, an operation generally called "scavenging." It was the improvement of exhaust systems and scavenging methods which led to high-performance two-stroke engines.

Notice that the exhaust port on this engine opens 26° before the transfer port opens, allowing an interval known as "exhaust lead" or "blowdown." The quickest way to understand the necessity for exhaust lead is to consider what would happen if it were not there.

At the end of the power stroke in an engine, pressure in the combustion chamber is still somewhere around 100 psi. The pressure in the case of a two-stroke is likely to be only around 20 or 25 psi when the transfers open. If the exhaust pressure has not been reduced by early opening of the exhaust port, then the exhaust will tend to travel down through the transfer passages and block the entry of new mixture.

The basic mechanism for the exhaust pressure to decrease is an opening through which it escapes, and a sufficient amount of time. The time interval represented by any particular amount of exhaust lead will of course vary with engine speed. Therefore, the designer selects an exhaust lead according to the intended RPM characteristic of the engine. The range of leads is from around 10° to around 30° before

the transfer port opens—with more lead provided for higher revving engines.

One of the things people do when porting a two-stroke is grind away at the exhaust port, making it larger so more of the exhaust can get out allowing more fresh mixture to enter, hoping that this will create higher combustion pressures and more power.

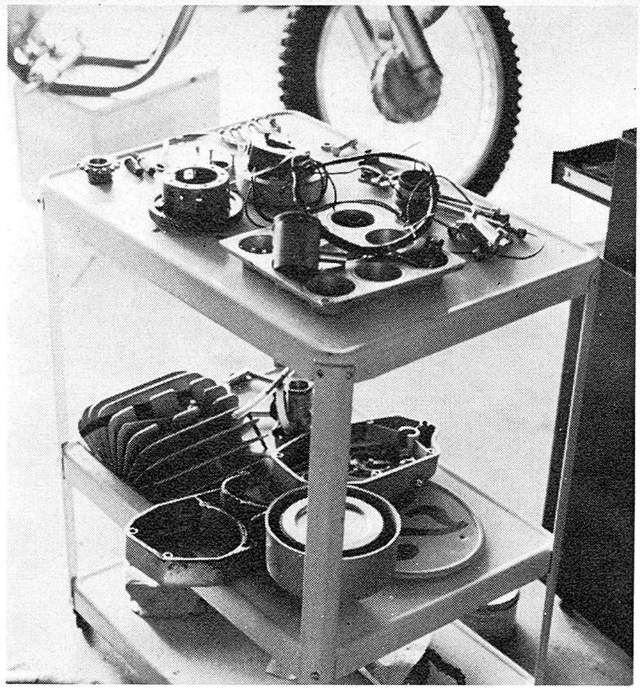
In grinding, you can make the port wider but this allows the piston ring to expand more into the open port as it passes by and the limit is the width which causes the ring to hang up on the edge of a port. This limiting width is usually stated to be around 60% of the bore diameter.

If it is at the limit of width, you can make the port larger only by moving the top or the bottom edge. If the top of an exhaust port is ground away, this will shorten the power stroke because the power extraction process stops as soon as the combustion pressure is vented to the outside. This is a neat balancing act. If the power stroke is made shorter, but a higher average pressure exists above the piston, then an increase in delivered power can result—usually at a higher RPM.

If you grind away at the bottom edge of the exhaust port, you can get a bigger passage without altering timing or lead. However it is likely that the engine designer got there first and positioned the bottom of both exhaust and transfer ports even with the top of the piston when it is at BDC. There is no point in grinding farther down than this.

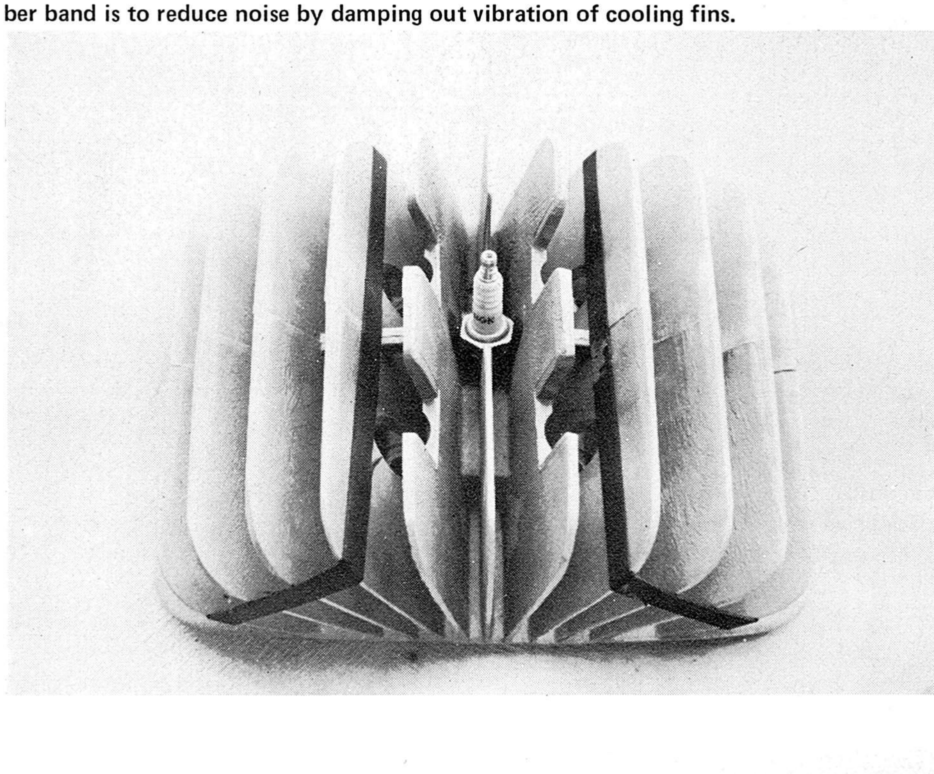
Most bike engines use a sleeve for the cylinder bore. The sleeve has the port openings machined into it and is then pressed into a casting finned for heat dissipation and which provides the needed mechanical strength and rigidity. If the openings in the sleeve do not match up with the openings cast into the barrel, then you may have a case for making it stock to begin with.

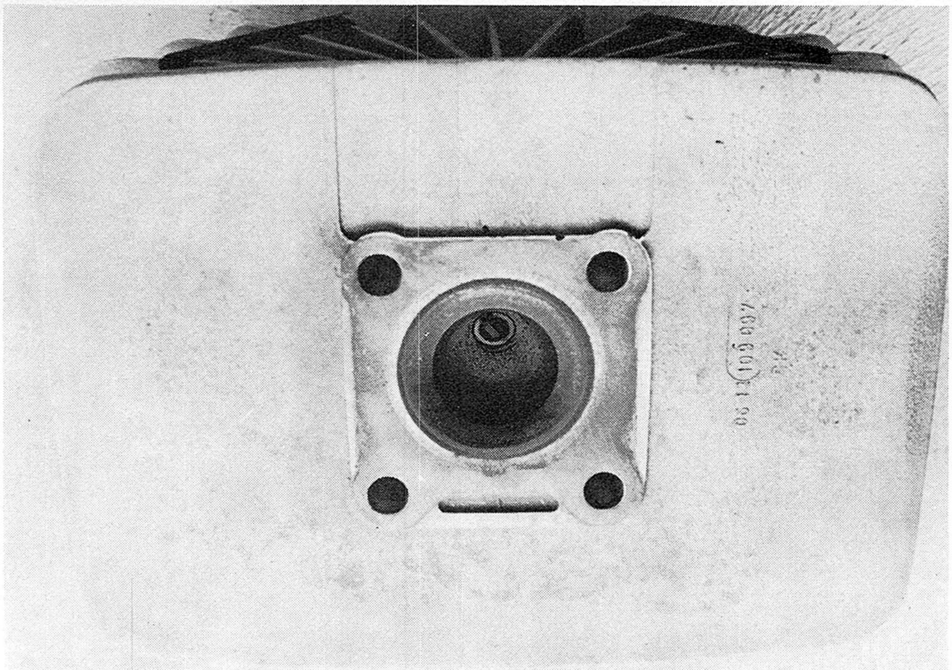
However, if you peek into the exhaust opening and see a dramatic misalignment such as 1/4 or 1/2-inch between the bottom edge of the exhaust opening in the sleeve and the hole in the casting, be wary. First, check to see if the piston, at the bottom, is lined up with the lower edge of the port in the sleeve. If so, there is nothing to be gained by removing metal. If the piston does actually travel



These are bits and pieces of a Sachs engine out of the skeleton in the background which will be a Monark motocrosser when it gets put back together. Main point of photo is to suggest that we sooner or later learn to get the parts off the floor, all in one place in some kind of order. Better to do it sooner. Engine is apart for gearbox work. While we are here, let's look at the ports.

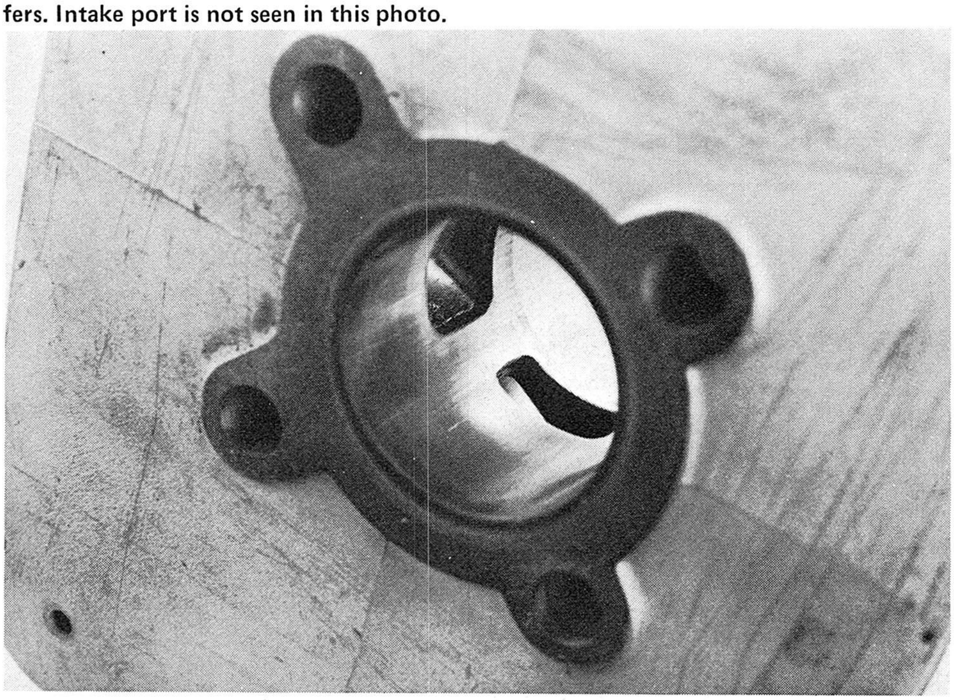
Engine is a conventional single-cylinder two-stroke with one centrally-located spark plug. This head design is called "radial" on account of the radially-dispersed fins. Rubber band is to reduce noise by damping out vibration of cooling fins.





Bottom side of head. Central cavity is combustion chamber. Tapered section surrounding combustion chamber is squish band—as piston rises toward TDC, squish band squirts mixture in toward spark plug. Plug is at top of combustion chamber and is slightly angled.

Top of cylinder. Highest port is exhaust. The other visible port is one of the two transfers. Intake port is not seen in this photo.



lower than the hole in the sleeve, then you are going to wonder why they left that ridge of metal sticking up in the exhaust passage and you will be greatly tempted to grind it away. Continue being wary.

If you change the design by grinding away this ridge of metal, you may be creating a thing called a "free port." Look again at the engine sketch of Figure 1 and imagine that the piston is all the way up to TDC. The skirt of the piston should be closing off the exhaust port. If the port is ground down below the skirt, then you have both inlet and exhaust open, *as viewed from inside the crankcase.* The mixture which is rushing into the case can go right out the other side into the exhaust pipe. In a real engine, intake and exhaust are usually opposite each other. I understand that this free-port arrangement is used to advantage in some high revving model airplane engines, but I don't think it benefits a motorcycle engine to get one accidentally. I made one once, by accident. I don't know what the result of the free port alone was because I made other modifications at the same time. The engine ran well. The bike was later sold and some lucky buyer got a free port, free!

The flow of a gas through a port is governed in part by the area of the port, the larger the better. When a designer battles all the limitations discussed above and still doesn't have enough exhaust port area to suit him, he makes two holes with a vertical bridge across the middle. The two ports may join together in the cylinder casting, and the bridge is streamlined to promote good flow. Resist the temptation to grind out the bridge. It is necessary to avoid trapping a ring.

TRANSFER PORTS

The quantity of mixture in a given volume is directly indicated by the pressure of that mixture. Our end goal is to get mixture above the piston at the highest possible pressure before the piston itself starts to compress it. Let's assume for a moment that the highest pressure available to the engine is atmospheric pressure. The problem then reduces to an apparently simple one. In drawing air in from the atmosphere we want to lose as little of that pressure as we can. This argues for a big carb and a big intake passage so the air can flow freely through without much pressure drop. When the intake port is closed that part of

the cycle is completed and what we have to work with is the pressure in the crankcase, whatever it is.

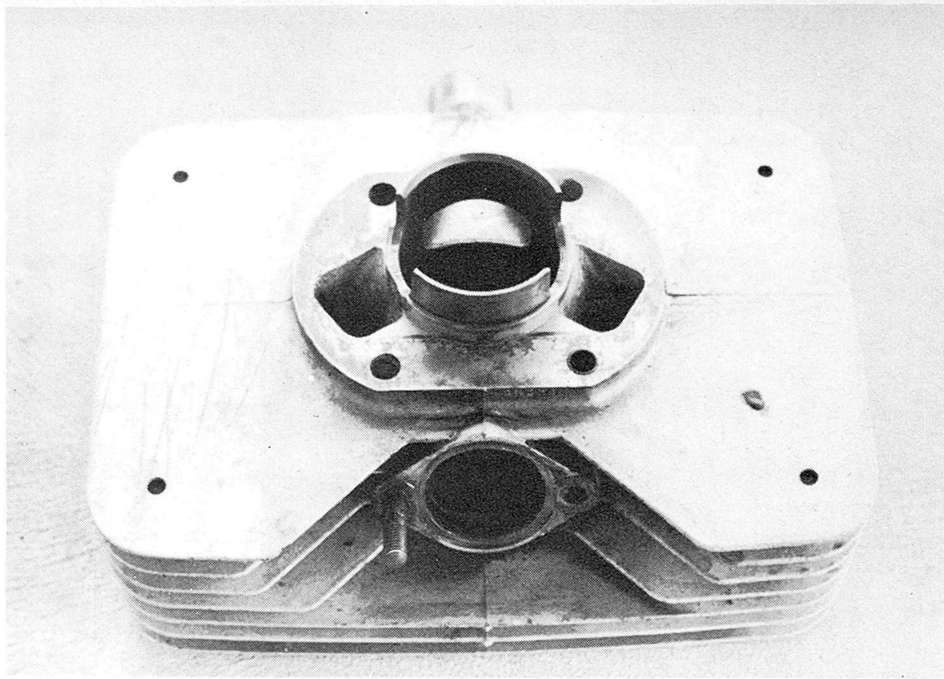
The next concern is to squirt that amount of mixture up through the transfer passages and get it above the piston with as small a pressure loss in the transfer passages as possible. This argues for lots of transfer area.

The main thing which causes the mixture to flow from the case is the increased pressure due to primary compression. Tuners often increase crankcase compression by a trick called *stuffing*, meaning putting metal (or something solid) every place they can to reduce the minimum volume. For example, if balancing holes are drilled in the crankwheels, they can be filled up with cork held in place by epoxy.

The size of the transfer passages has an effect on case compression because the transfer volume is part of the minimum volume of the case. Another trade-off. If you enlarge the transfer area to aid transfer and reduce pressure loss, you automatically get less case pressure to push the mixture through those larger passages.

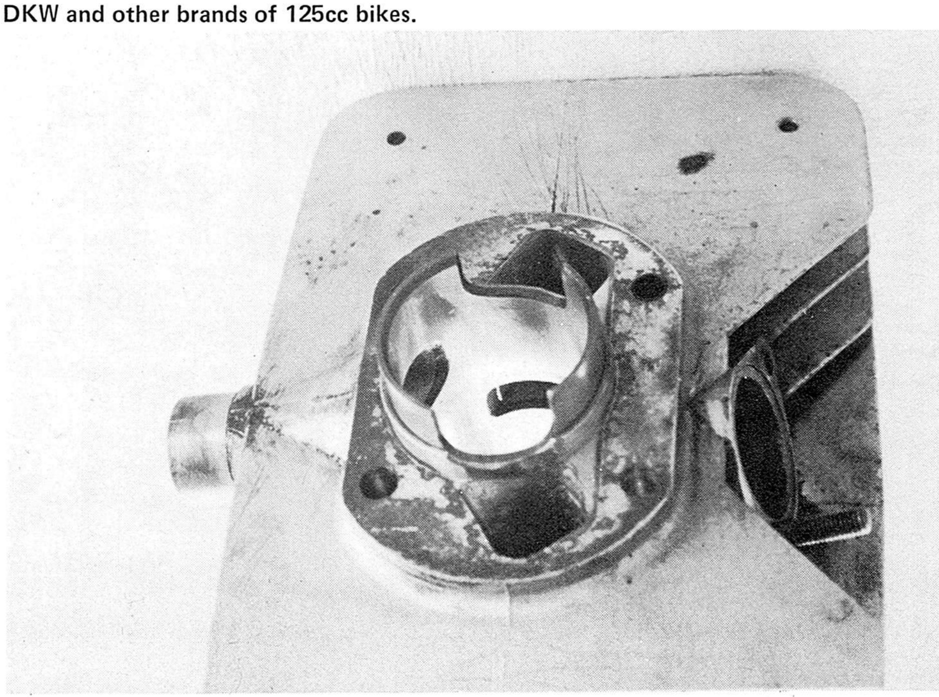
Compounding the problem is the fact that, like most other happenings in a two-stroke, mixture transfer from the case to the combustion space accomplishes two things at the same time. First, it gets new mixture up there. Second, the new mixture is introduced so it pushes out the exhaust products from the previous combustion cycle. The simplest modern two-stroke engines use two transfer passages, on opposite sides of the engine, arranged so the two streams of mixture flow toward the back of the cylinder, join together, sweep up the back, across the top, and then move down toward the exhaust port, as shown in Figure 2. This is called *loop-scavenging* and some smarties refer to it as the Schnurle design because Herr Schnurle is credited with its development. As much as 10 or 15 percent of the fresh mixture can go right on out the exhaust port while scavenging is taking place.

In high performance engines, additional transfer ports are employed, also for two possible reasons. The first is simply to aid the transfer process. A second is to aid cooling of the piston head by drawing away the stagnant pocket of mixture trapped inside the piston and replacing it with cool fresh stuff.



Cylinder "barrel" viewed from the bottom. Exhaust flange uses two studs to hold on pipe. One of the studs unscrewed during removal—doesn't matter, it will be replaced on reassembly. Carb spigot mount is visible on far side of barrel, leading to intake port in cylinder wall. Bottoms of both transfer passages are at left and right.

Same barrel viewed from side. Intake at left. On far side you can see bottom and top of one transfer passage. This engine is stock. Modifiers enlarge ports, add reed valves, boost ports, finger ports, and other secret stuff. This engine is also used on Penton, DKW and other brands of 125cc bikes.



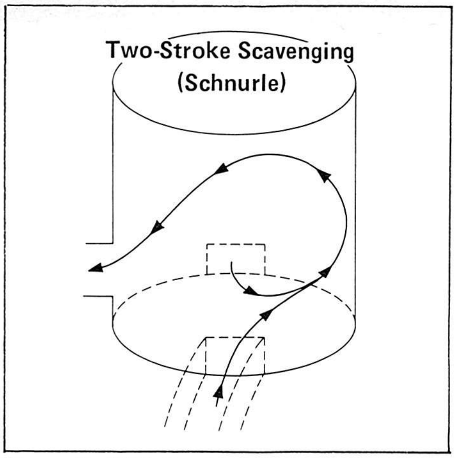


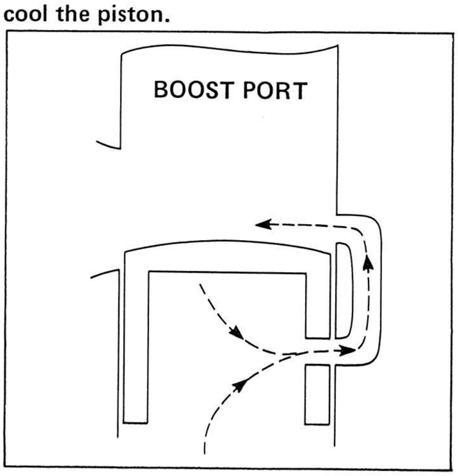
Figure 2—With the loop-scavenging method, the flow of fresh charge into the cylinder is directed so as to sweep out the exhaust products from the previous combustion event.

Additional transfer ports must be located so that the flow of mixture from them will help the flow from the main ports in performing scavenging. One good arrangement places a third transfer port, often called a "boost" port, at the rear of the cylinder directly opposite the exhaust port. Room is provided by splitting the inlet tract into two paths.

This port is arranged to communicate with a hole in the back of the piston, as shown in Figure 3. When the holes line up, the compressed mixture under the crown of the piston flows out and upwards through the third port.

The possibilities for perforating the barrel in different ways are nearly limitless and the avid hole-puncher is defeated only when he encounters one of the absolutes of nature: You can't make a hole in a hole.

Figure 3—Additional transfer ports, sometimes called "finger ports" may aid the scavenging process. If a port draws mixture from beneath the piston, it also helps to cool the piston.



Small channels are ground into the cylinder liner, called "finger ports." The top of the port peeks over the top edge of the piston near the bottom of the stroke and a squirt of fresh mixture comes out. Sometimes this mixture is intended to flow directly across the top of the piston so as to provide a little extra cooling to the piston itself. Or else the flow from the finger port is directed so it helps with the scavenging process. Or else it has some other secret function which the guy who made the hole won't disclose.

The most important process in a two-stroke is scavenging because if that doesn't happen, nothing else will. When the exhaust system is doing a good job of pulling out the combustion residue and the flow pattern from the transfer ports is doing a good job of pushing it out the back door, then the engine sings bravely. If you put on a pipe that doesn't work, it's easy to change back to the one that did. If you make some ill-advised holes, the standard remedy is a classified ad.

"Leaving for Europe instantly. Must sacrifice speedy racer with extra-trick engine mods. Unbelievable. . . ."

Evidently the number of ports has some influence on sales because manufacturers continue to announce more and more ports in their new offerings. This may or may not have significance. Basically, there are three port functions: inlet, transfer, and exhaust. Any of these tracts can be divided into more than one and the transfer function is nearly always done by at least two passages.

If an engine has a divided inlet tract, a divided exhaust passage, two conventional transfer passages, plus a third transfer feeding through a hole in the piston, all of these holes could be added up and the result announced as a miraculous 7-port engine. The only really significant additional port, in terms of function, would be the third transfer.

TIMING THE TIMING

We have seen event timing in Figure 1, displayed as degrees of crank rotation. Another way to measure this timing is in the actual time as might be shown by a super-fast stopwatch. The actual time represented by any number of crankshaft degrees will vary with engine speed, as you know, becoming shorter as speed increases. This is shown in the following table:

EVENT TIME IN SECONDS

RPM	120°	140°	160°
3,000	0.0067	0.0078	0.0089
6,000	0.0033	0.0039	0.0045
12,000	0.0017	0.0020	0.0022

These numbers are calculated using the proportion:

$$\frac{\text{Time of event}}{\text{Time per revolution}} = \frac{\text{Degrees of event}}{360^\circ}$$

Notice how short these time intervals are. For example, if 120° is allowed for intake, at 3,000 RPM this is only 0.0067 seconds and at 6,000 RPM it is half-again shorter. A time of 0.001 second (a thousandth of a second) is called a millisecond. We are providing time intervals ranging from around one to around ten milliseconds for a complete event to take place in the operation of the engine.

Speaking of these short time intervals is not entirely to provoke you into saying "Golly!" although you may if you wish. It is mainly to introduce the musical portion of this entertainment which follows immediately.

If you are unobserved at this moment, please hum out loud a musical note, about as high as your voice will hum. The note you made has a frequency of somewhere near a thousand cycles per second. The resulting sound will travel through the air as a train of pressure variations, similar to waves in water. If a thousand of these pressure variations is happening in one second, then the time for any one of them is a millisecond. This physical fact will help us in getting sweeter music out of an engine. We'll use it shortly when we start talking about tuned exhaust systems.

RAM EFFECT

The gases in an engine, mixture and exhaust, are caused to move in three different ways. The first is simple pumping action. If we move the piston and open a hole to the outside, the piston will act as a pump and either draw air in or expel it. The second method is a by-product of the first. If, by pumping action, we get a column of air in motion, then it will display

the property of inertia. Inertia means that an object at rest tends to stay at rest and it takes a force to start it moving. Inertia also means that an object in motion tends to stay in motion, and it takes a force to stop it.

Imagine that an inlet is opened and the piston is moved so as to draw in air. When the piston reaches the far limit of its travel its effectiveness as a pump ceases. However, air continues to rush in due to the inertia of the air column. The extra air brought in by this "ram" effect can raise the pressure in the cavity to some value higher than atmospheric. The next thing it will want to do is turn around and rush back out. If the engine is clever enough to close off the inlet while the pressure inside is still above atmospheric, then it has benefitted from the ram effect and has achieved a higher internal pressure than simple pumping action alone could have accomplished.

This is the reason inlet passages are allowed to stay open after piston pumping action has reversed. At some RPM, all of this is working just right and the engine closes off the inlet just at the peak of pressure. That RPM is the torque peak of the engine.

In an exhaust system, even with a plain straight pipe, ram effect works in reverse. The column of gas in the pipe will tend to pull residual gases out of the combustion space, and usually some of the fresh mixture as well.

ACOUSTIC TUNING

The big problem in a two-stroke is getting the exhaust out of the cylinder. We invite a portion of fresh and attractive mixture to come into the engine, take it upstairs and proceed to engage it in a hot interlude. We allow it to dissipate most of its energy in forcing the piston down nearly to the bottom. Then, we open the door and ask it to please leave. With its energies nearly spent, the exhaust doesn't happily rush out into the cold. So the incoming fresh charge gets behind it and kicks it out. And we design an exhaust system which grabs hold of it and pulls it out.

The most effective way to pull the exhaust out is to use a tuned pipe. This is tuned in much the same way an organ pipe is tuned—by length, size, and shape.

What happens is something like this: When the exhaust port opens some of the gases flow out due to the remaining pressure in the combustion space. Then some inertia or ram effect starts working and continues to tug at the exhaust gases. Then the acoustic tuning gets in the final coup.

The initial pulse of gas into the exhaust head-pipe creates a pressure pulse in the pipe which travels as a *sound wave* and at the *velocity of sound* toward the end of the pipe. If the pipe is a simple length of plain tubing then, at its end, the pressure pulse is reflected back toward the engine and, very helpfully, is changed to a negative pressure pulse—meaning reduced pressure rather than increased pressure. When this pulse gets back to the exhaust port the reduced pressure will extract more of the exhaust gases from the cylinder—*if* the port is still open.

To keep it simple, if we decide that on some engine the exhaust port is open for a millisecond, then the sonic pressure wave has to leave the port, travel to the end of the pipe, change to a negative pressure pulse, and get back just before the port closes. If so, the travel time of the sound wave in the pipe is a millisecond and the pipe is tuned, or resonant, at the audio frequency of a thousand cycles per second.

Nothing in the foregoing is hard to accept as truth, except that the overall proposition is unbelievable. It is easy to see that when the exhaust port opens, some positive pressure emerges into the pipe. The unbelievable part is that the thing goes to the far end, becomes negative, and then hurries back to help out.

The booger is the polarity change (positive to negative) at the end of the pipe. It's difficult to explain in words, but let's take a whack at it.

One way is to observe that as the increased pressure pulse exits at the end of the pipe, it expands suddenly into the open atmosphere. Due to the inertia of the individual particles of gas in the pulse, this lump of pressure will expand too much, creating a partial vacuum.

Now there is a volume of reduced pressure just outside the end of the exhaust pipe. This causes the layer of gas which is barely inside the pipe to rush forward to fill the vacuum ahead of it. When that layer of gas moves forward suddenly, it creates a reduced pressure just behind it, so the next layer rushes forward. Now there is a reduced pressure area two layers back inside the pipe. It will then move to the third layer inside and by this mechanism it will travel all the way back to the exhaust port.

If you convince more readily by analogy and you own a piece of rope, you can watch a similar thing happen. Tie one end to a post, hold the other end in your hand, and flip a wave into the rope. The wave will travel away from you, toward the post. At the post, the wave will be reflected back toward you.

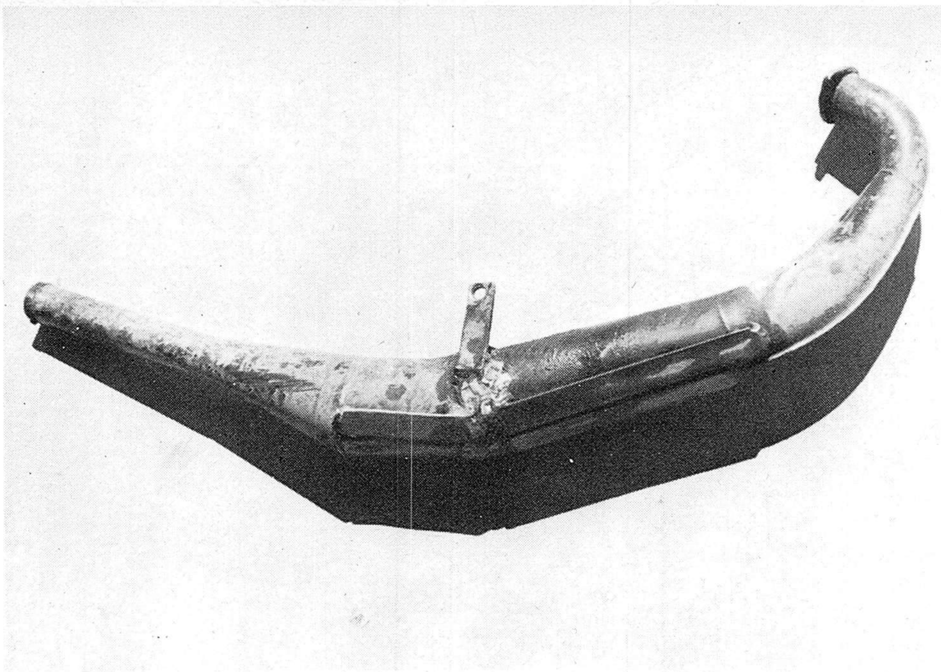
What's been said so far is, a plain pipe dumping directly into the atmosphere will send back a reduced-pressure pulse (negative pulse) which can aid in the extraction of exhaust if it gets back there while the door is still open. This can happen only over a narrow range of RPM and it is customary to tune the pipe to the engine rather than vice versa. By cutting pipe to different lengths, the power peak of an engine can be shifted on the RPM scale. Four-stroke engines are sometimes helped this way and sometimes use a plain pipe with a megaphone on the end. What the megaphone does will be apparent in a minute.

If we now expand our understanding of reflections in a pipe, and make some simple rules, we can take a closer look at a sophisticated expansion chamber for a two-stroke.

If a positive pressure pulse is romping along in the pipe and encounters a barrier or *restriction*, that will also cause a reflection and the returned pulse will have the same polarity—that is positive. The reasoning is opposite to the case where the pulse encountered open atmosphere.

If an exhaust pipe, somewhere along its length, is given a larger diameter, that is *similar* to dumping into open atmosphere but the effect is not as great. A negative pulse will reflect back from this larger section but the pulse will not be as strong as the open-atmosphere case. The advantage of enlarging the pipe but still confining the gases in it is, we can do some more tricks. There is still some energy in the pipe and that part which was not reflected is still rushing toward the rear end of the exhaust system.

If we let the pressure wave travel some distance in the enlarged length of pipe and then *reduce* the diameter again, that will cause yet another reflection of pressure back toward the ex-



Every time a pipe changes diameter, a pressure-reflection can occur. If the change is gradual—cone shaped—the reflection pulse is spread out and the engine will have a wider power band. In this expansion chamber for a two-stroke there are three reflection points. After the curved head pipe, the diameter gradually becomes larger; then the pipe tapers down again to the stinger; then the stinger dumps into open air which can create the third reflection.

haust port of the engine. This reflection will be *positive.*

The rule is: **Any change in cross-section of a pipe will cause a reflection.** Multiple changes cause multiple reflections, each taking some of the energy but not all of it.

Now we can begin to appreciate how smart a pipe maker has to be. Look at the accompanying photo of an expansion chamber and you will see three places for reflections. The pressure wave leaves the exhaust port and goes some distance along a pipe of uniform diameter. Then the pipe expands, causing a negative reflection. Later the pipe gets smaller again, causing a positive reflection. At the very end of the pipe, after traveling through a final straight length called the "stinger," there is another negative reflected pulse. This is all done on purpose and all of these reflections are useful.

It takes a lot longer to write it, or read it, than it does to understand it. So if you will please understand slowly we can travel in happy harmony, thee and me, wending among these fragrant paragraphs.

The first reflection, from the cone at the beginning of the chamber, has to get back to the exhaust port while the port is still wide open or at least not closed up very much. It helps yank out stuff. If the port is open for one millisecond, then the round-trip time for this pulse has to be less than a millisecond.

Now the logic gets devious. If the extraction process in the cylinder is working really well, then near the end it will have pulled out most of the exhaust products and will be extracting some fresh mixture and continuing to reduce the pressure in the combustion chamber. We may not care about losing fresh mixture but we do care about losing pressure in the cylinder because that is part of the compression of the next charge.

The reflection from the cone at the far end of the chamber helps out. It should arrive just as the exhaust port is closing, poke some of the escaping fresh mixture back inside, and increase cylinder-head pressure at the instant the exhaust port is sealed off. If the exhaust interval is a millisecond, this positive reflection should get back just before the end of that period.

There is still another reflection on its way back from the end of the stinger, but the exhaust port is already closed. You guessed it! This reflection is delayed until *the next time* the exhaust port opens. It arrives shortly after opening and because it is a negative pulse it starts yanking out exhaust early in the inning.

Obviously the timing of all these reflections has to be precise and the resonant exhaust can be effective over only some narrow range of engine speed—the power band. If a reflection pulse can be spread out so it exists for a longer time interval, then exact synchronism with the engine is less critical and the power band is wider. That's the reason for the cones in the pipe. A reflection will occur from any change in section. If the pipe diameter changes suddenly, the reflection will be sudden and of short time duration. If the reflection is gradual, then the pulse is wide and occupies more time. The cones cause gradual reflections and a wider power band.

It's nice occasionally to derive some practical ideas from all this swimming around in murky theory. So here are a couple.

Just by changing the pipe, you can greatly alter the performance characteristics of an engine. If the engine is peaky, the power comes on suddenly and you don't like it that way, changing the pipe may fix it. On an engine designed for absolute maximum power both intake and exhaust systems will resonate at the same RPM, the intake poking it in while the exhaust jerks it out. It won't look that way because the velocity of sound is less in the cold intake mixture than it is in the hot exhaust. So the intake dimensions are shorter.

If you make the exhaust resonant at some lower engine RPM, the power peak will be lower but broader. Pipes to do this are sold as "torque pipes."

Low RPM power is benefitted by a long head pipe. If you want a still calmer engine, use a long head pipe dumping into a mildly tuned chamber or even a muffler. Trials bikes and some enduro bikes are made this way.

On the other hand, if you are after a big lump of high power and you modify your two-stroke engine to get it, the power will be there at a higher RPM. To get the most benefit from the engine mods you will need a pipe which is tuned to a higher RPM. Most successful two-stroke hop-ups require both internal changes and a different pipe.

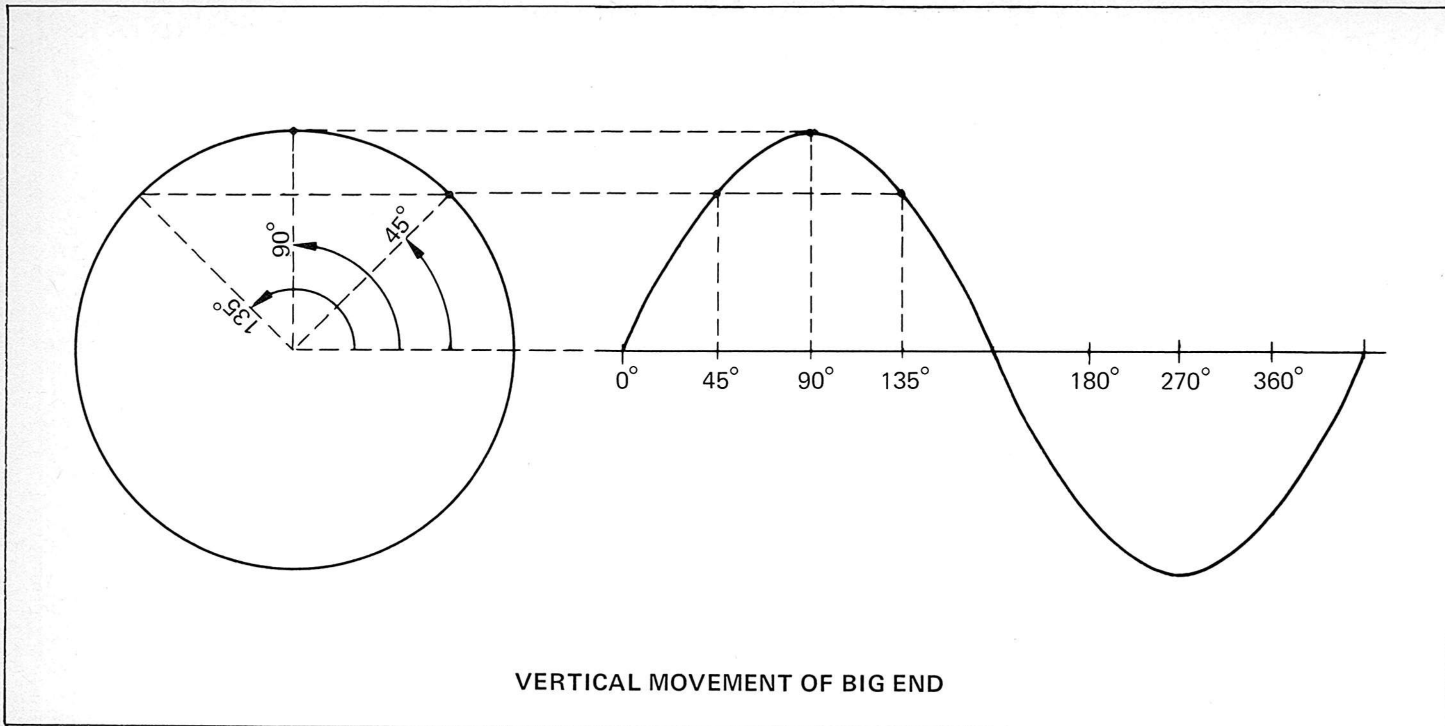


Figure 4—By a simple graphical construction, the up and down movement of the lower end of the con rod can be displayed against crank rotation.

There are only a few places in the world where tuned pipes are designed by formula. It takes a computer and a lot of elegant computer programming. Dr. Gordon Blair at Queens University, Belfast, Ireland, is one of the acknowledged experts in this field and even he probably does some "cut and try" before he is through. The average pipe builder uses less arithmetic and more cutting and trying. The average *rider* just does the trying. You buy a custom pipe according to the maker's reputation and then see if it is better.

Now we have to back up for a minute and think about the four-stroke. You know what the megaphone does. The four-stroke designer needs little help from a tuned exhaust to aid in closing off the exhaust port because he has a valve to do that. He can close it anytime he wants to by cam contour and timing and is not burdened by the intrinsic symmetry of port events in a two-stroke. That's the main reason four-strokes benefit less from an expansion *chamber* in the exhaust.

DWELL AT TOP AND BOTTOM

Because the piston changes direction at each end of its travel it must obviously stop entirely for an instant. Since it also slows down just before it stops, and then speeds up after it has changed direction, we can imagine that the piston hangs around in the vicinity of TDC and BDC for a little while each time it visits the place. This is called "piston dwell" and if you have never thought about it you might think the dwell would be the same at both places. Not so. The piston actually hurries away from the top but likes to loiter at the bottom. The mechanical reason for this strange behavior is the connecting rod and with a little Euclidian detective work we can build a solid case against the con rod.

Figure 4 shows a circle which represents the path traveled by the crank on a crankshaft. The bottom end (big end) of the con rod also follows that circular path. If you look at it from the end of the crankshaft, you will see the big end moving around in a circle. If you look at it from a point 90° away, all you will see is the big end moving up and down by an amount which is the piston stroke.

It will be helpful to find a way to display this vertical motion of the big end as the crankshaft rotates. This is done in Figure 4 by picking a point on the circle and imagining that it starts at some zero line and rotates counterclockwise. As the point rotates, and moves upwards from the zero line, we project its *height* over to a chart and show the height against a scale marked off in degrees.

The first point indicated above zero is 45°, and the height projection is shown as a point on the resulting curve. The next point shown on the diagram is 90°, along with its projection. Similarly, 135° provides a vertical height the same as it was at 45°, and so forth.

If enough points are plotted by this method, the curve shown is the result. It is called a sine wave and is a graph of the vertical motion of the big end of the con rod, at all angles of crank rotation. In other words, it is the pattern of motion of the big end. This pattern shows some dwell at top and bottom and it is evident that the dwell is the same at top and bottom. We haven't found the bad guy yet.

Now we are going to think about the movement pattern of the upper end of the con rod (small end) which is also the

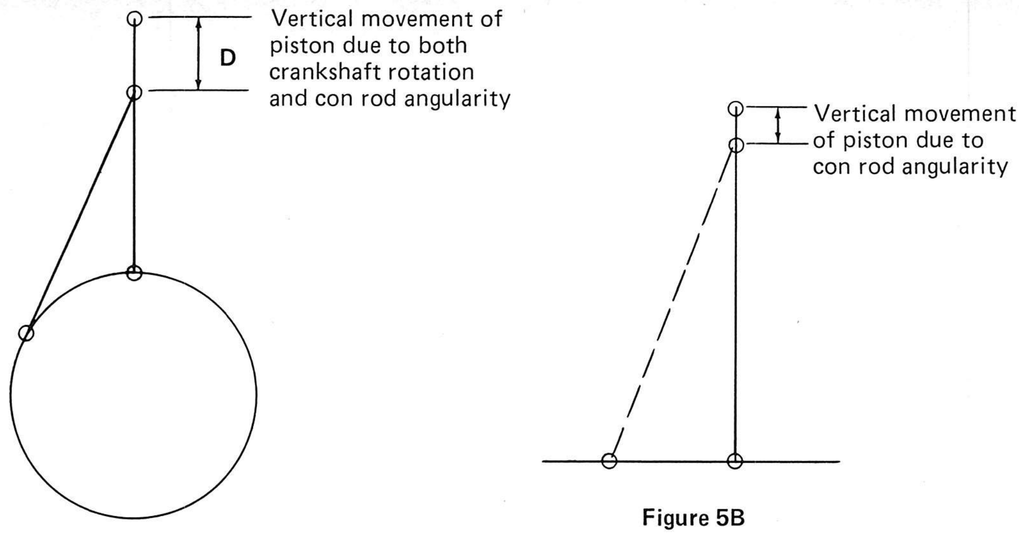
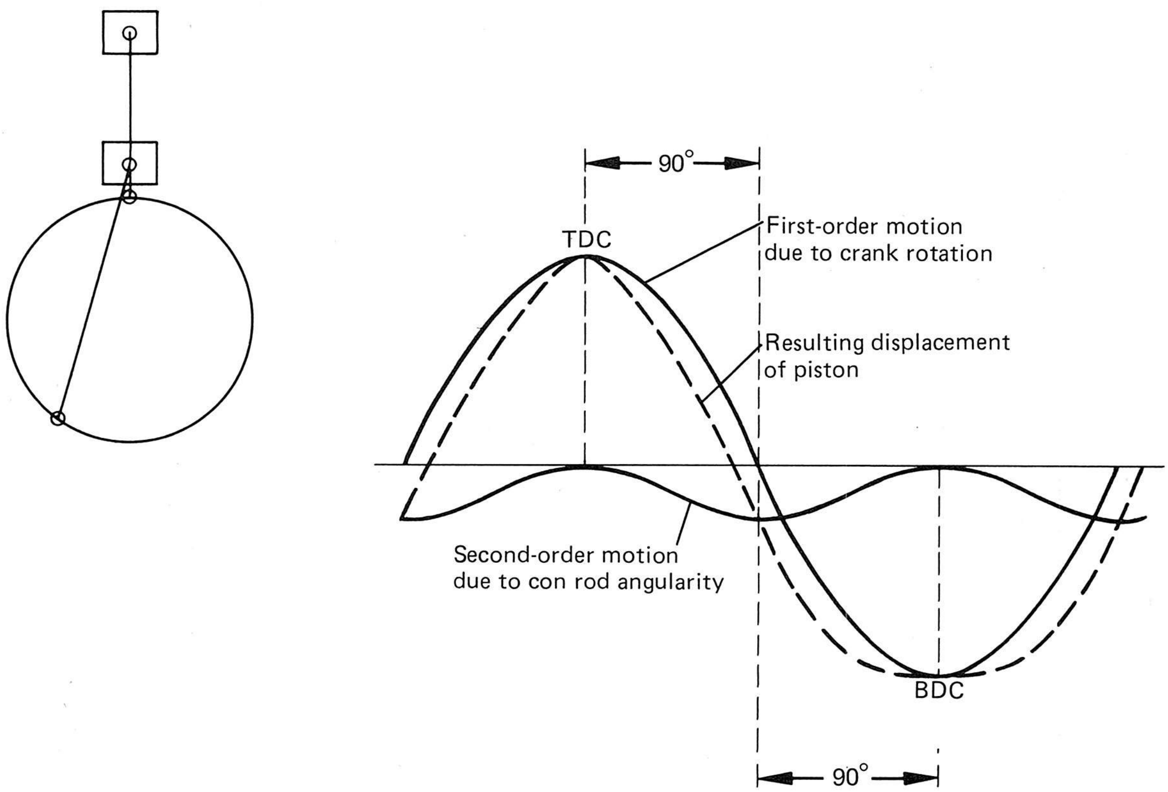


Figure 5A
CON ROD ANGULARITY

Figure 5B
EFFECTIVE SHORTENING OF
CON ROD DUE TO ANGULARITY

Figure 5—Because the con rod assumes different angles as the crankshaft rotates, the effective length of the rod is changed.

Figure 6—When the basic up and down motion of the crankpin is altered by the angularity of the con rod, the pattern of movement of the piston is affected. It dwells longer at the bottom than it does at the top.



pattern of the piston. This is complicated by the fact that as the big end moves up and down it also moves from side to side, horizontally, as it travels around the circle. This places the con rod at an angle with respect to a vertical line and this angle varies according to the position of the crankshaft.

In Figure 5A, the con rod is shown at an angle. The upper end, where it is connected to the piston, travels in a straight line vertically, while the lower end is moving both vertically and sideways. When the small end has been pulled down some distance, D, that distance is the sum of the movement caused by the basic crank rotation and the movement caused by the con rod assuming an angle. We already know the contribution caused by rotating the crankshaft, it is a sine-wave pattern. If we can determine the contribution caused by tilting the con rod, we can add these two motions together to find the complete pattern of motion of the piston.

Figure 5B shows a way to do this. The solid line is the con rod when it is vertical and the dotted line is the rod when it is at some angle. Obviously its *vertical* height is less when the rod is angled, like leaning a ladder against a wall.

The arithmetic is straightforward, however we don't need to do it. We can sketch the outcome, as shown in Figure 6.

The first-order motion of the piston is the sine curve. The second-order movement is due to con-rod angularity. At TDC there is no angularity, so this motion is zero. At 90° of engine rotation away from TDC, the effect of rod angularity is maximum and it is plotted in the negative direction because it makes the rod effectively shorter and therefore pulls the piston down. At BDC the rod-angle effect is again zero because it is not inclined. At another 90° of rotation, the rod effect is again maximum and it, again, pulls the piston down.

The effect of con-rod angularity always tends to make the rod act as if it were shorter. The frequency of this motion is double the crank-rotation frequency.

The total piston movement is the sum of these two motions and that is obtained graphically simply by adding the two curves together. The resulting curve (shown by the dotted line) represents the actual vertical motion of the piston plotted against crank rotation. The pattern near TDC has become peaked, whereas the shape of the curve near BDC has become flattened.

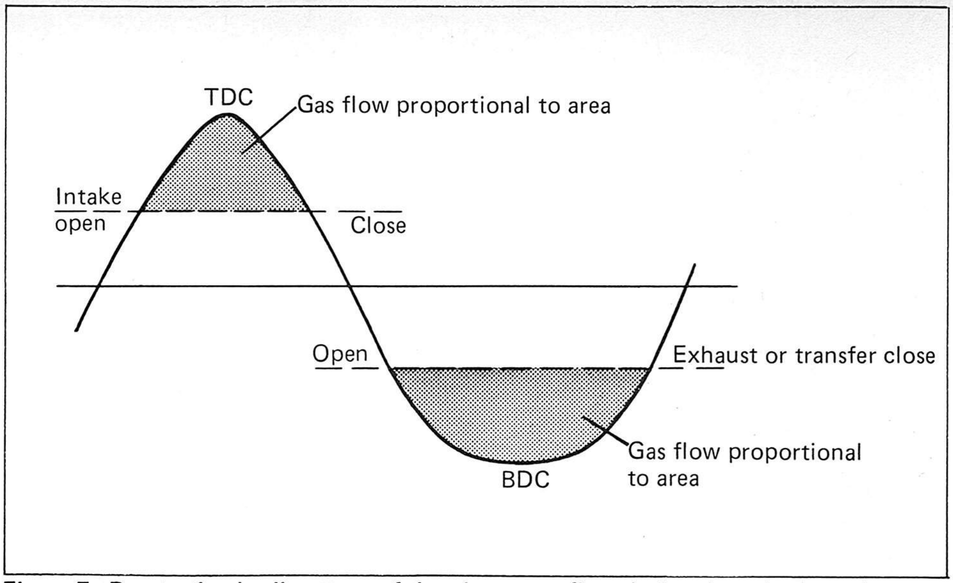


Figure 7—Due to the dwell pattern of the piston, gas flow during the exhaust and transfer events is aided while intake is handicapped.

Because the vertical movement of the piston opens and closes the ports, Figure 7 shows the pattern of piston movement with some dotted lines drawn across it to represent positions where ports are opened and closed.

The volume of mixture that can flow through a port during its open period will be proportional to the *area* enclosed between the curve and the appropriate dotted line.

Degrees of event duration do not tell the whole story. Exhaust and transfer actions are favored by the shape of the piston-motion curve, whereas intake is handicapped. This means in practice that the designer makes the carburetor and intake passages as big as he needs to for the engine. The exhaust and transfer passages can be a little smaller than they would be if the piston motion was truly a sine-wave pattern.

PISTON SLAP

In Figure 8 a piston is shown being forced down by the combustion pressures. Because the rod is at an angle, the downward force is divided into two components. One is along the length of the rod and the other is horizontally-directed into the side of the bore, again like a ladder leaning against a wall. This causes higher wear of both piston and bore on that side.

Due to this increased force against one part of the cylinder wall and the resulting wear, clearances get bigger and piston slap begins to occur. This is just what the name implies. The piston is slapped against the barrel each time combustion takes place.

As this side force is caused by rod angularity, many engines are designed to reduce the amount of con-rod angle during the power stroke. Referring again to Figure 8 and noting the clockwise rotation of the crank, if the center of the crankshaft were moved to the left, the rod would take a smaller angle and the side force against the barrel would be reduced. Or the piston pin can be located to the right of center in the piston. If so, installing the piston correctly is essential, and this is why some pistons are marked for front and rear.

Offsetting the piston pin, or crankshaft, will reduce piston slap. It will

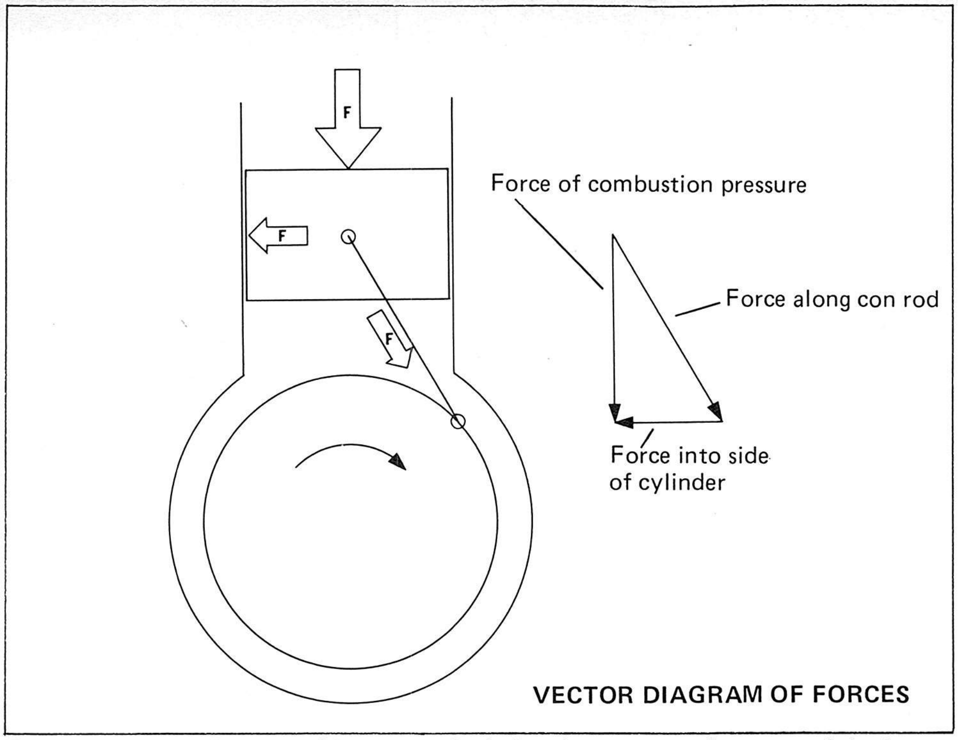
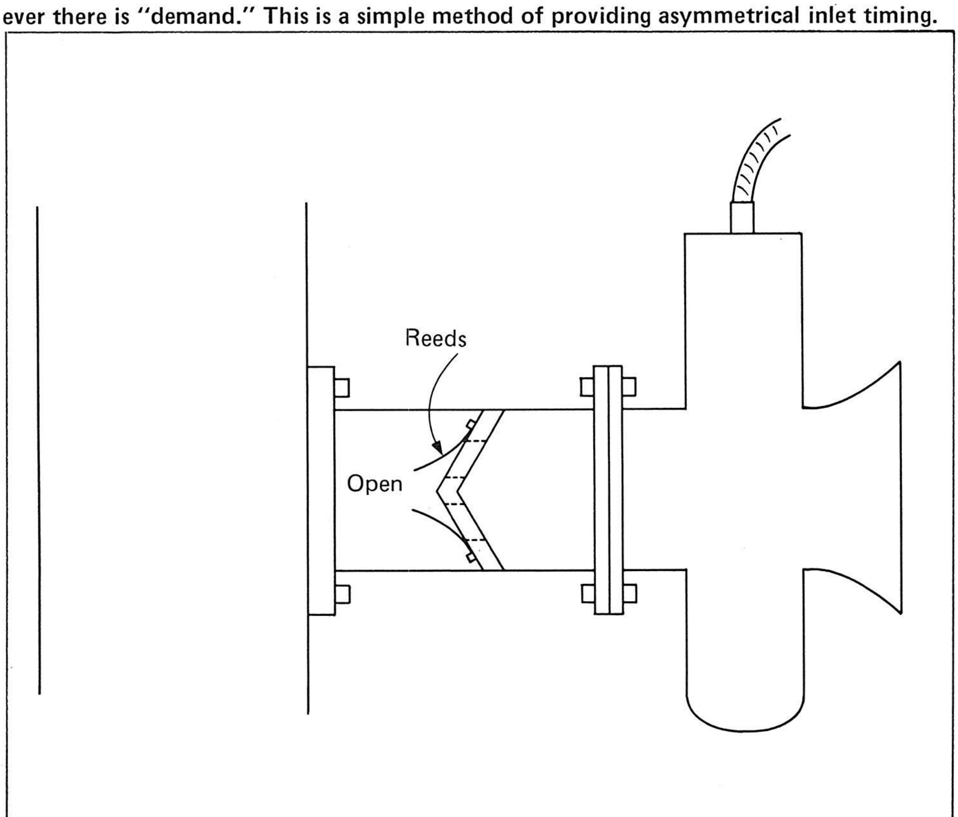


Figure 8—Because the con rod is at an angle during the power stroke, some of the force of combustion is exerted against the wall of the cylinder resulting in increased wear and eventual piston slap. Piston-pin offset, or crankshaft offset, is used to reduce the con rod angle on the downstroke.

Figure 9—Reed valves react to crankcase pressure variations allowing fuel-air to enter whenever there is "demand." This is a simple method of providing asymmetrical inlet timing.



also increase the force on the opposite side of the barrel, however forces are smaller on the upstroke anyway.

Offsetting will also change the pattern of motion of the piston. If you want to reconstruct the drawing of Figure 6 with some pin or crank offset you will see that the piston-motion curve becomes distorted and the port timing becomes a little bit asymmetrical.

ASYMMETRICAL TIMING

It is desirable to provide as much time as possible for mixture to be drawn in and also to leave the inlet tract open long enough after TDC for ram effect to take place.

If the best time to close the inlet is, say, 66° ATDC then with symmetrical timing the inlet cannot open until 66° BTDC. That allows a very short time for the inlet function and it would be better to open the inlet port sooner. This would allow more time for the crankcase to fill which would reduce air velocity and therefore pressure losses in the carb and inlet passage.

REED VALVE

A reed valve provides asymmetrical inlet timing. As shown in Figure 9 it is simply a flap (or flaps) in the inlet system which opens or closes according to the pressure difference across it. When there is a crankcase depression, the reed opens and allows fuel-air to flow in. When the pressure in the case starts to reverse and cause outward flow, the reed closes.

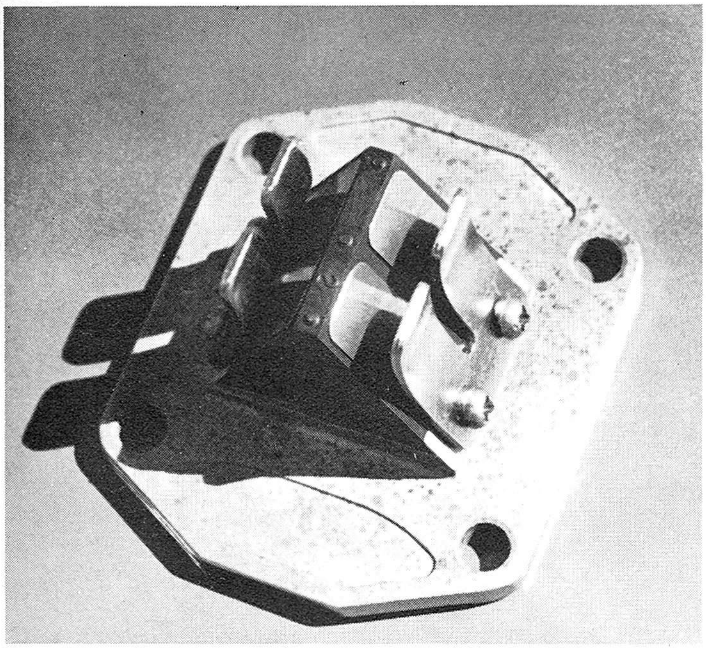
Because the reed is now opening and closing the inlet, the piston skirt should not interfere in the operation. The skirt is cut away, or sometimes opened up with "windows" so that it can never obstruct or close off the port.

Reed valves are available as accessories with adaptors to fit many engines. A reed makes an amazing improvement in the low-RPM performance of an otherwise peaky engine.

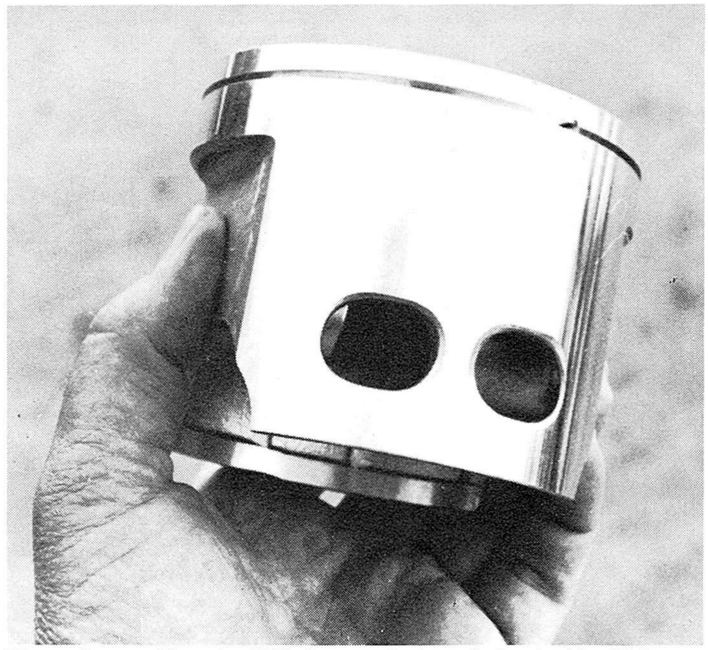
The reed and its support structure offer some restriction to flow and reed valves tend to work better when the entire intake system is designed or carefully modified to accommodate the presence of the reed.

ROTARY VALVE

A rotary valve can also provide asymmetrical inlet timing. It is a disc mounted on the end of the crankshaft, as

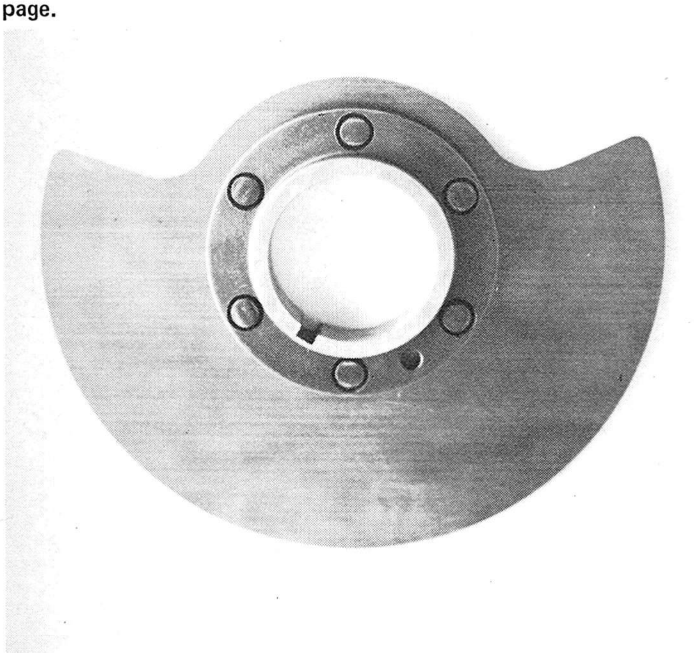


Yamaha reed valve assembly uses four reed "petals," two on each side. When closed, petals rest against triangular block, as shown, covering four holes. Reed petals and triangular block point toward crankcase. Mixture flow is from opposite side, through reed assembly to this side. When there is crankcase depression, petals pull away from plastic center structure, exposing the four holes and allowing mixture flow. Curved metal pieces on outside of reed petals limit the travel of the petals when they open up and also cause them to bend over a smooth arc so they are less likely to break.

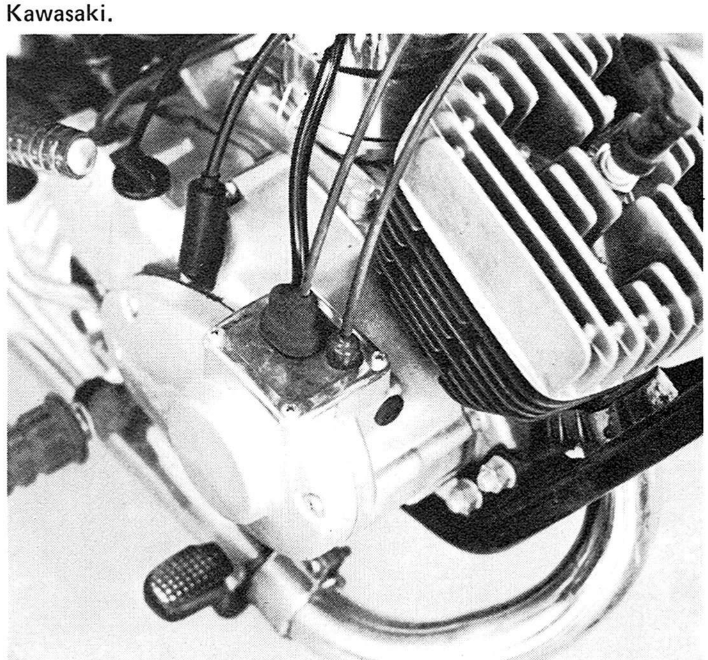


Piston from a Yamaha 500 shows windows in back side. This piston is used with a reed valve. The holes in the piston allow the reed to control induction as described in the text.

Another way to get asymmetrical inlet timing is a rotary valve driven by the end of the crankshaft. See drawing on opposite page.



When a rotary valve is used, the carburetor is often placed just outside the rotary valve, down by the end of the crankshaft. If so, the engine side-case is made a little wider to enclose and protect the carb. Throttle and automatic oiler controls go into top of side cover where the carburetor lives on this rotary-valve Kawasaki.



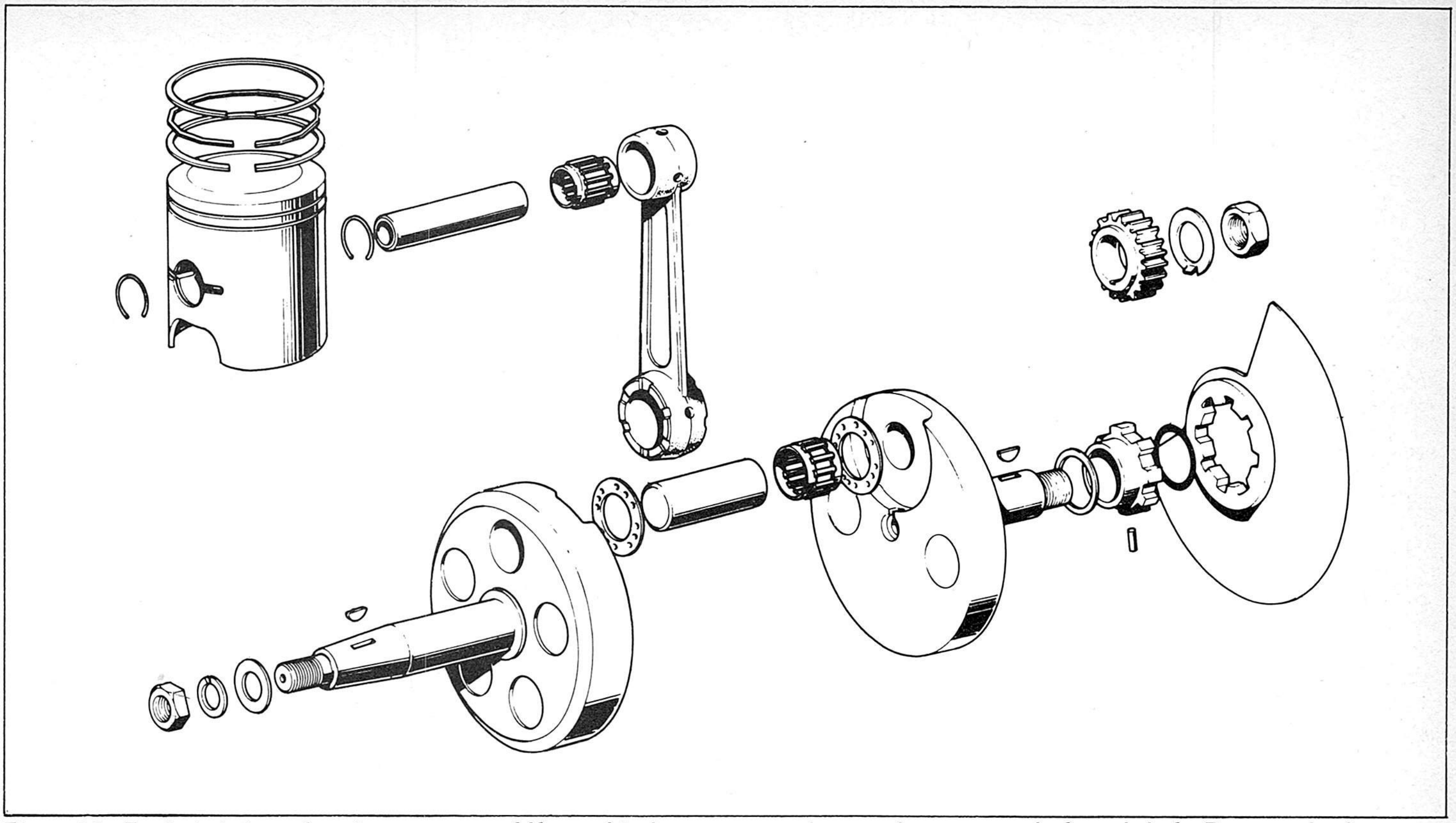


Figure 10—Exploded view of engine, courtesy of Kawasaki, shows rotary valve attachment to end of crankshaft. Rotary valve is outside of the crankcase. When cut-out portion of rotary valve passes by a hole in the crankcase (not shown), mixture can be drawn into case. Thus inlet timing is achieved by the leading and trailing edges of the wedge in the rotary valve. Timing does not have to be symmetrical, which is an engineering advantage over a conventional piston-controlled engine.

shown in Figure 10. A wedge is cut into the disc, through which mixture flows on its way into the crankcase. Inlet timing is governed by the wedge's dimensions. Typically, a rotary valve allows intake to commence at around 120° BTDC and then will close off the inlet system at about 60° ATDC.

It is common to mount the carb in a housing just outside the rotary valve which makes the engine case wider on one side than on the other. The carb can be mounted anywhere as long as the inlet passage is routed through the rotary valve, but this makes torturous inlet passages.

CONGRATULATIONS

Since this is not intended to be a book on the design of engines, that is probably more than enough on two-strokes. If it helps you get a better feel for what a particular mod is likely to do, and if it highlights for you the intricate relationships among the various happenings in a two-stroke, then it has served the purpose. If this has whetted your appetite so you want to read more on the subject, then congratulations are in order. To me.

There are some good books on the subject. Some of those I have scratched at, occasionally flaking off a tasty bit of intelligence are:

Motorcycle Engineering by P. E. Irving
The High Speed Two-Stroke Petrol Engine by Phillip H. Smith
Carburetors and Carburetion by Walter B. Larew
The Sports Car by Colin Campbell
Two-Stroke Ports for Power by Roy Bacon
The Two-Stroke Engine, Design and Tuning by K. G. Draper.

There are quite a few more good books which are readily available. It's true, I think, that there are more good books on automobile engines than on bike engines. However, the engine usually doesn't care much what it is installed in and the info you can read about car engines is often directly applicable to any other engine.

FOUR-STROKE ENGINES

As you can see, we are doing it all backwards. Having discussed the two-stroke first, all we have to do now is think about some of the differences encountered in four-strokes.

The first, obviously, is that the engine only uses the top side of the piston to effect movement of the gases. The next obvious difference is that four-strokes typically use poppet valves in the head, both for intake and exhaust, and there is not any transfer function because the mixture is drawn directly into the combustion space.

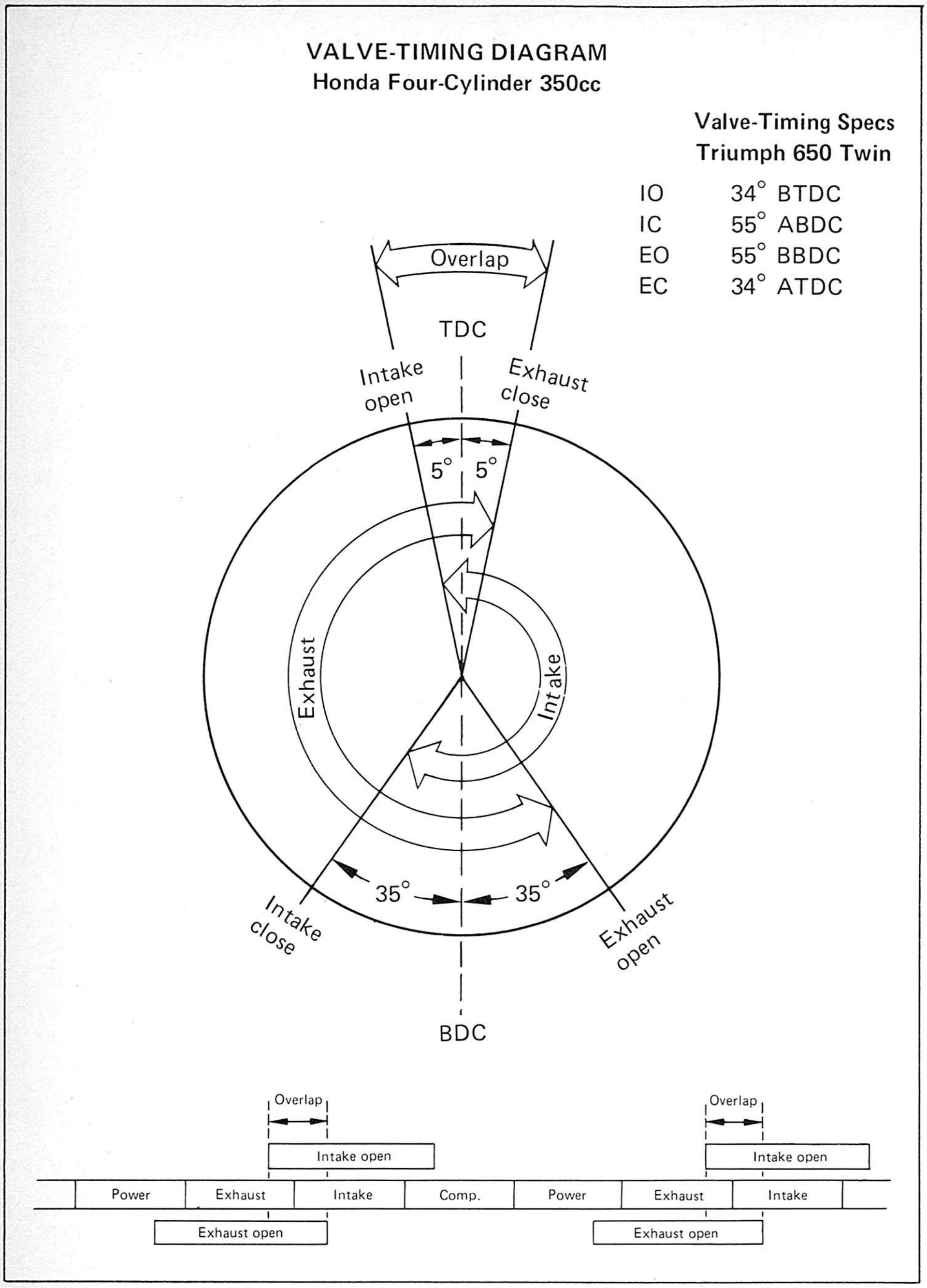


Figure 11—Valve-timing diagram for a Honda Four and valve-timing specs for a Triumph Twin. Timing of the Honda is more conservative. Notice that valve overlap occurs only at TDC. Not at BDC because intake and exhaust are open on different revolutions at BDC. To clarify this, valve and piston event drawing at bottom of figure shows valve overlap only when both intake and exhaust are open at the same time.

The valves are spring-loaded toward their closed position and are pushed open by a camshaft when desired. This can allow asymmetrical timing both of inlet and exhaust very simply, governed by the camshaft opening and closing angles.

A valve-timing diagram for a 350cc Honda Four is shown in Figure 11. Also in the figure are the specs for a Triumph 650 twin, for comparison.

Notice that the Honda's intake opens before TDC. One reason for this is simply to give the camshaft a little head start in pushing the valve open so that when it really needs to be open, as the piston starts moving downward, it already has appreciable area for gas flow. Since the early opening on this engine is only five degrees, this is the main reason.

The intake is left open for 35° past BDC for reasons you already know. One of the things people talk about when describing the characteristics of a camshaft is the duration—which means valve-opening duration expressed in degrees. In this case, the duration is 220° (5° + 180° + 35° = 220°).

The exhaust opens at 35° before BDC, which means that the extraction of power on the downstroke ends at that point. However, if you remember the top and bottom dwell patterns of a piston, you know that the piston has already completed most of its vertical motion and is just hanging around down at the bottom. By opening the valve early, some blowdown of exhaust is allowed in advance of the pumping action of the piston which will then force the remainder of the exhaust products out the exhaust port. If some of this gas is allowed to escape in advance, then less work is required in order to pump out the remainder.

The exhaust is left open until 5° after TDC mainly to be sure there is some effective opening still available at TDC so the piston can expel more of the residual exhaust. The 5° also allows some minor bit of ram effect, but the interval is not long enough to depend heavily on ram. The "tuning" represented by this camshaft is very mild, as you will see.

Another characteristic of camshafts is called overlap. In this example, the overlap is the ten degrees near TDC when both intake and exhaust are open at the same time. When overlap is more than

this modest amount, the purpose is twofold. It is to get some strong extractor effect from the exhaust system and also to allow this tug from the exhaust pipe to reach across the top of the piston and pull in fresh mixture from the intake side.

In an inverted way this begins to sound something like the gas dynamics in a two-stroke. It also hints that four-strokes are not as simple as some textbooks would have you believe.

There isn't any overlap at BDC on the valve timing diagram, even though it looks like it at first glance. The events at BDC are happening on different revolutions of the crankshaft.

Duration and overlap are both determined by the "ramp" on a cam—that is they are established by the points where the valve is just opening or just closing. The remaining cam characteristic which is normally stated is the amount of lift, which governs how far the valve is lifted off its seat and therefore affects the volume of gas flow.

From here it gets a little tricky. For example the combination of duration and lift determine the acceleration, deceleration, and accompanying wear factors. We will touch on one aspect of this in a moment.

The two camshaft specs given in Figure 11 are for a mild cam (the Honda) and for one on the border of race-tuning. Triumph's 68° overlap and 269° duration allow it to be manageable on the street, but it *is* a pretty lively engine. These two engines also illustrate the RPM advantage of an overhead cam (OHC). Honda's OHC arrangement allows it to develop peak power at 9,500 RPM whereas the pushrod Triumph peaks at 6,700 RPM.

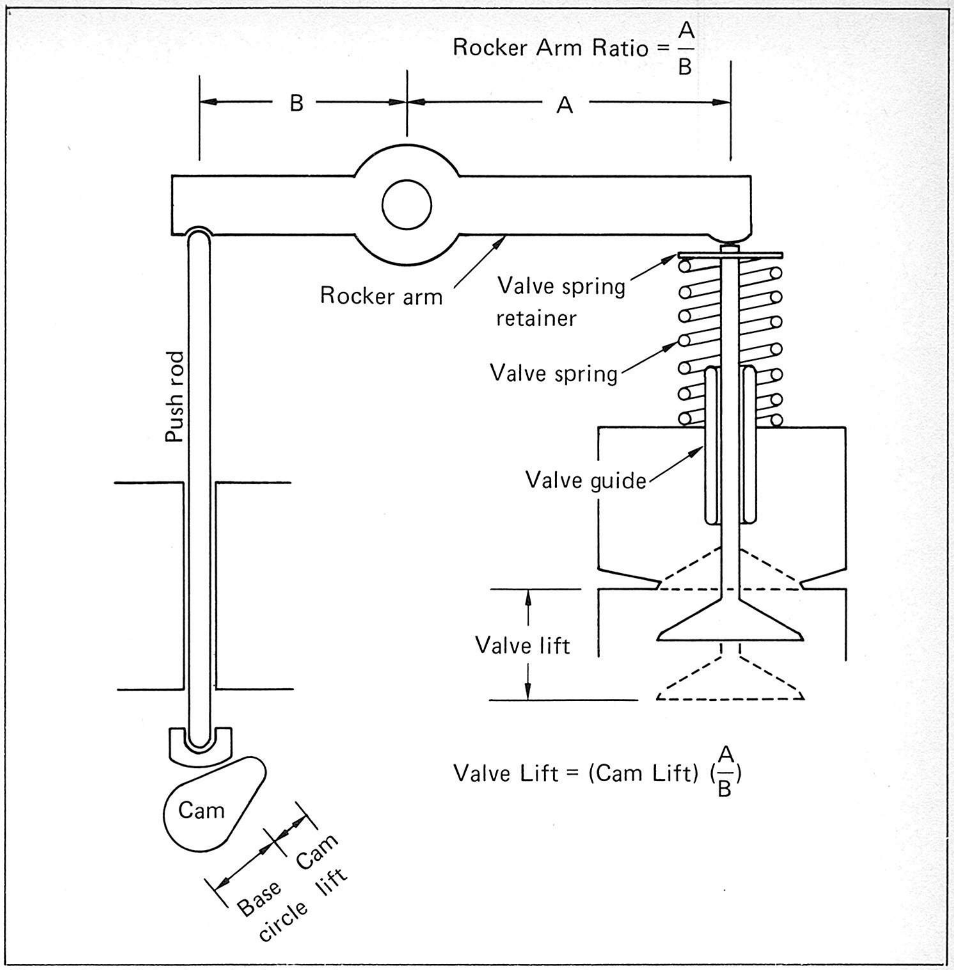


Figure 12—This sketch shows the usual arrangement of pushrod-type overhead valve engines. The rocker-arm ratio multiplies the cam lift and the result is the actual lift of the valve off its seat.

VALVE FLOAT

A poppet valve and the spring which holds it closed will vibrate at some natural frequency, if twanged and then left alone. If the weight of the valve is made less, or the spring stronger, the resonant frequency of the combination increases to some higher value. It is desirable to have the natural frequency high, so valve trains are made as light as possible and valve springs are made as strong as is reasonable.

In building an engine it is convenient to put the camshaft down by the crankshaft and use pushrods to reach up where the valves are. However pushrods add to the reciprocating weight of the valve system and they also flex. Some engines eliminate the pushrods by putting the camshaft up on top of the engine and operating the valves more directly. As mentioned above, an OHC engine will usually operate at a higher RPM than a pushrod engine.

If other factors do not limit the maximum RPM of an engine, the valve system eventually will by falling victim to a condition known as valve float. This means that the valves are not following the contour of the cam and are not opening and closing as they should.

To understand this requires consideration of two topics: forced vibrations and natural vibrations. If a valve is set on its spring, the spring compressed a little and then released, the valve will move up and down, oscillating at its natural frequency, and will always take the *same amount of time* to travel from one extreme to the other.

A valve in an engine will always move at its natural rate whenever it is allowed to, but it can be *forced* to move at any other speed. When the camshaft is opening the valve, it is compressing the valve spring and, in effect, getting the valve system set to oscillate.

When the cam is moving away from the valve, the valve may or may not follow the contour of the cam.

If the *natural* speed of motion of the valve, when being urged closed by its spring, is faster than the camshaft is allowing, then the motion of the valve is *forced.* It is being forced to go slower than it would if the cam were not in the way.

If at some high RPM the cam is moving away from the valve at a speed higher than the natural speed of the

valve assembly, then the valve will simply ignore the cam and close at its own natural rate. If you imagine that the valve never did get closed before the cam came around next time to knock it open again, then you are visualizing an extreme case of valve float. Engines don't run well that way, so valve float establishes an upper limit to engine RPM.

VALVE TRAIN GEOMETRY

A mechanic who is a semi-skilled "parts changer" will take a four-stroke engine apart and, when putting it back together again, spend possibly a half-hour assembling the valve train. A knowledgeable and serious tuner may spend half a day or more on the valve system alone.

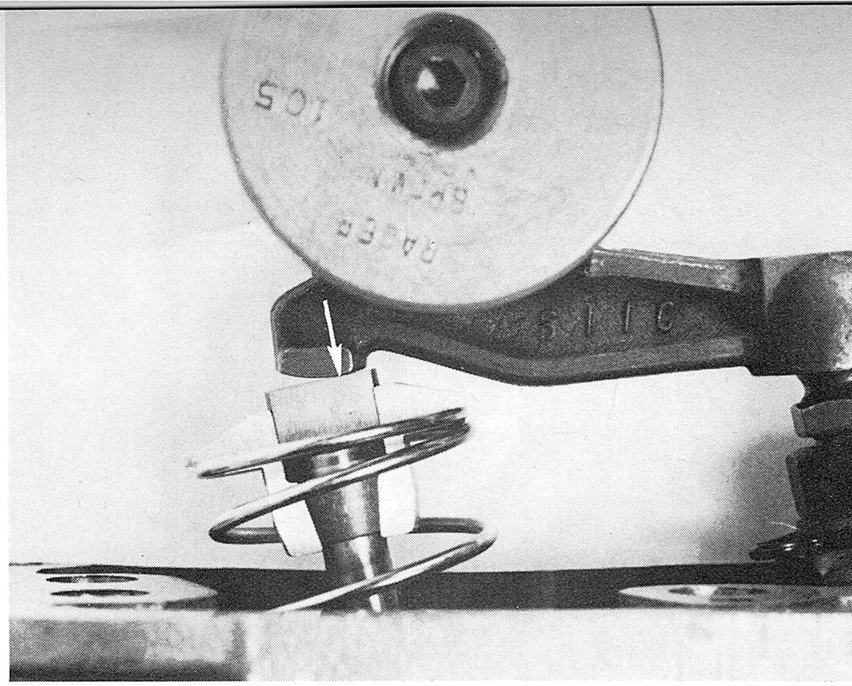
The basic reason for the careful assembly by the good guy lies in the geometry of the mechanism, and the fact that parts change due to wear or rework and have some manufacturing tolerances to begin with. It seems like nothing is ever quite as simple as it appears. One component of an engine can affect the operation of several others and sometimes the effects are both obscure and important.

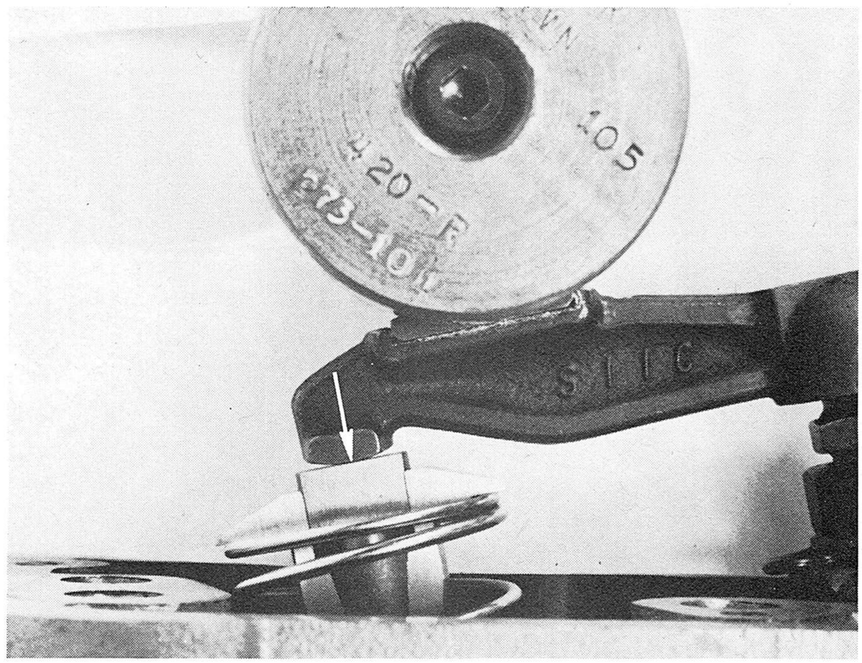
To begin, consider a pushrod valve system as sketched in Figure 12. The cam can be thought of as a circle to which a lump of metal has been added causing the cam itself to have some lift when the nose of the cam operates to move the pushrod. A cam profile is also illustrated in Figure 12.

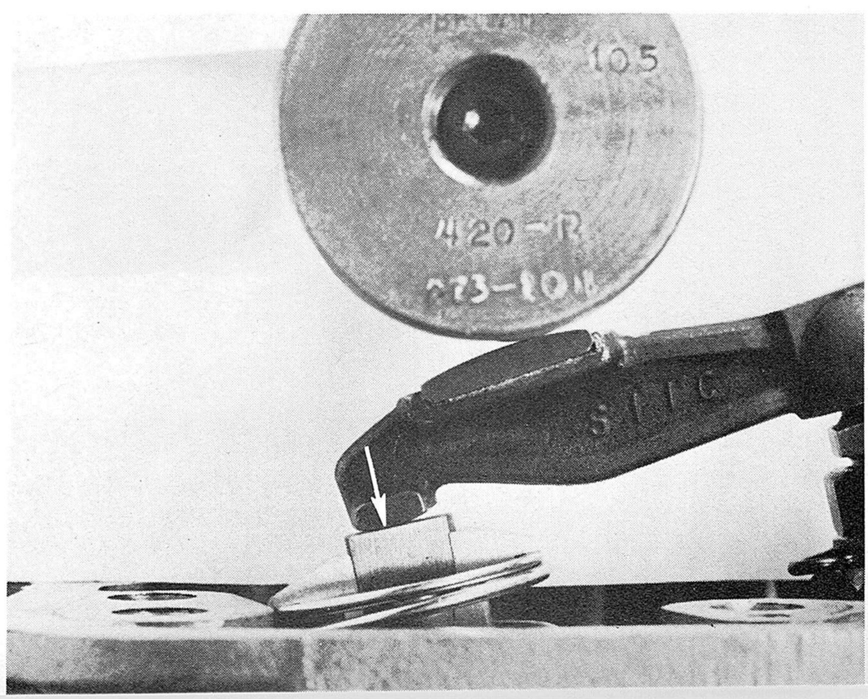
The pushrod transmits linear motion to one end of the rocker arm which pivots on a fulcrum—the rocker-arm shaft. The other end of the rocker pushes down on the valve stem and opens the valve.

The amount of movement or lift of the valve is governed both by the shape of the cam and the rocker-arm ratio. On the drawing dimension A is the center-to-center distance from the valve stem to the pivot and B is a similar measurement over to the pushrod. Ratio A/B multiplied by the cam lift gives the amount of valve lift, assuming that the valve actually is following the contour of the cam.

Because the rocker is moving in an arc while the tip of the valve stem can move only straight up and down, it is obvious that the rocker tip must move across the top of the valve stem while opening the







valve. And therein lurks one of the reasons your engine may make white smoke and burn oil.

In order to prevent the rocker tip from sliding across the valve stem, the rocker is usually rounded so it tends to roll across rather than skid across, reducing the side force applied to the valve stem. Sometimes a spacer or pad is put in between the valve stem and the rocker however if the spacer is supported by the valve stem any side force applied to the spacer is transmitted to the valve.

ROCKER ARM GEOMETRY

The end of a rocker arm moves in an arc of a circle. If you imagine for a moment that it rotates in a complete circle, then you can see that when it is passing across the top of the circle most of its movement is horizontal. In order to get some vertical motion from it, the top of the circle is not the place to go. When a rocker arm is 90° around from the top of its circle, that's the place to use it to operate a valve because most of its motion is in the up and down direction.

This means that the rocker arm should make a right angle with the valve stem at the *point where the valve is halfway open.*

Rocker arms have peculiar shapes and sometimes it is difficult to tell just by looking exactly where the centerline of the rocker is. If it has a rounded tip which rolls across the top of the valve, then the line of contact between rocker and valve stem will move across the top of the valve during operation, as shown in the accompanying series of pictures.

In the top photo, the valve is closed and the contact point is on the right side of center. When the valve is half open, the contact point is on the centerline of the valve stem, and then the contact moves on across the valve tip as the valve is fully opened.

If you can see this contact point and also measure valve movement, then set up so what you see looks like the center photo at half lift. If you can't see the point of contact then you have to figure out some other way such as eye-balling the rocker arm to judge when it is at right angles to the stem.

This is the setting that will give maximum valve lift and therefore best engine performance. What if you check and it isn't that way? You should fix it if you can and if you are after that last little bit of performance. The way to fix it varies according to the design of your engine. Study the layout and the drawings and photos in a shop manual and you should be able to find a way. Some things to consider are:

- Grinding the valve stem to make it shorter.
- Selecting among new valves to find a stem of the correct length.
- Pads of varying thickness between valve and rocker.
- Changing the height of the rocker-arm pivot by shims or by adjustment if there is one.
- Changing pushrod length on a pushrod engine.
- Altering the height of the camshaft.
- Your own great invention.

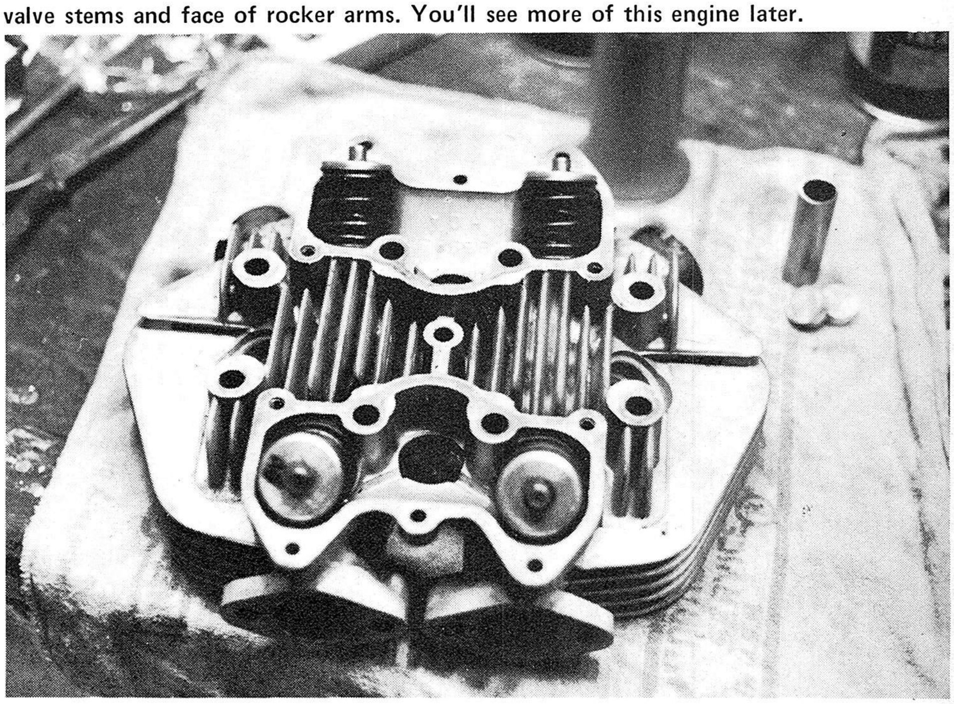
When you are installing a new camshaft or new valves, you should pay particular attention to this and get it as near right as you can. Then your scooter runs well for a long time and finally needs a valve job. You have the valve seats refaced and lap in new valves or clean up your old ones and use them again. Yep, the rocker-arm action on the valve stems isn't right anymore so you have to fix it again.

I made a calculation to see how much benefit you actually get from setting up this way. For the worst case, I assumed that the rocker got the valve fully open just as the rocker arm reached the ninety-degree angle with the stem. For the best case, the ninety-degree angle was reached at the midpoint of valve travel. The lift when it is set up right is about one percent more. That doesn't sound like a lot but the message is not that the valve lift is more at the end of its movement. The valve is lifted higher during the *entire* period of valve opening and the result will show up on a dyno. Anyway, kids, it's free power if you take the trouble to get it.

VALVE GUIDE WEAR

The other problem resulting from a rocker arm pushing on a valve stem is side force. When the contact of the rocker is anywhere *other than on the centerline* of the valve stem a side force is generated which tends to tip the stem in the valve guide. The hole in the valve guide is worn into an elliptical shape and doesn't seal well anymore. On each intake stroke,

This is the head of a push-rod two-cylinder twin. Push rods come up each side, through holes between valves, operate rocker arms. Rocker arm assembly bolts on top, not shown. Valve springs are held on valve stems by keepers at top of each stem. When engine is assembled, valve clearance will be measured between top of valve stems and face of rocker arms. You'll see more of this engine later.



oil will be drawn into the cylinder resulting in white smoke, excessive oil consumption and spark plug fouling if the condition gets bad enough. The fix is replacement of the valve guides, normally a shop operation.

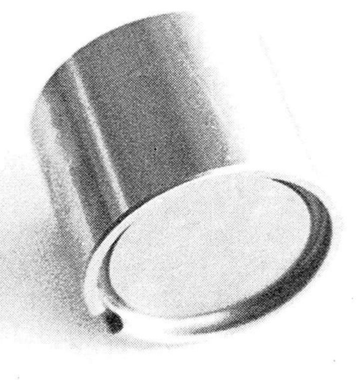
Because side force on the valve stem occurs only when the rocker is not at right angles to the stem, the same set-up procedure which results in maximum valve lift also tends to minimize valve guide wear. A question can be raised that this arrangement puts the mechanism in balance *geometrically*—that is the angle between rocker and stem is about the same at each extreme of travel—but seems to ignore the fact that the rocker has to push harder on the valve as it opens up more because the valve spring is being compressed. This suggests that geometric symmetry may not be the best setting to minimize valve guide wear. However the situation isn't that simple. There are accelerative forces acting on the valve in addition to the force of the spring. Sliding wear is a complex and variable process.

Therefore you should tailor a rocker arm valve mechanism for maximum lift as described above.

Another way you can lose your proper valve setup on a pushrod engine is to mill the head for more compression. When you put it back together, the rocker-arm shaft will be closer to the camshaft by the amount that was milled off the head and the pushrods don't need to be as long as they were before. You can shorten them. Alternatively, you can raise up the rocker arm shaft by putting a spacer under it. The thickness of the spacer depends on the amount the head was milled and the rocker-arm ratio. Even by shimming up the rocker arm assembly, complete correction cannot be made unless you also shorten the pushrods. You can make a simple sketch to show why.

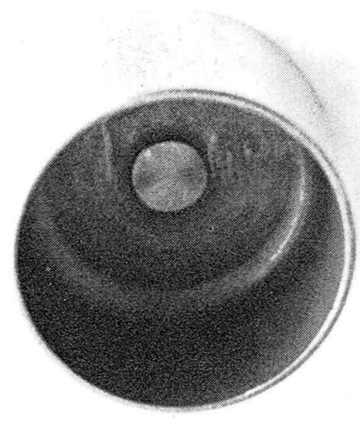
VALVE LASH

In all mechanical valve systems some clearance is allowed between the parts when the valve is closed. The cam will first take up the slack, or lash, and then begin to open the valve. The basic reason for this is to be sure that the valve is actually closed when it is supposed to be closed. Imagine that a pushrod is engaging the base circle of a cam, the valve is just barely closed, and all the slack has been adjusted out of the linkage. Then, if either the pushrod or the



On the Kawasaki Z-series four-stroke engines, valves are operated by an overhead cam. This "bucket" fits over valve stem and moves up and down in its own bore, which keeps side-loads off valve stem. Shims of varying thickness are placed in cup on top of bucket to adjust valve lash. Cam lobe works against hardened shim. Lash is adjusted by measuring, then changing to a shim of different thickness if required. Notch in side of bucket allows reaching in to remove and replace shims, when valve is pressed away from cam by special tool. Exploded view of this engine is on page 154.

Looking into bucket from the bottom. Ground and finished boss on underside is where valve stem makes contact.



valve stem becomes longer due to thermal expansion, the valve will be lifted off its seat.

Valve lash can be measured anywhere in the linkage by "collecting" all the slack at that point and measuring it with a feeler gage. It will be more, or less, on the push-rod side than on the valve side according to the rocker-arm ratio.

The lash can also be adjusted to the manufacturer's specs in a variety of ways, according to the design of the particular engine. In a pushrod system the adjuster is typically a screw threaded through one end of the rocker arm with a lock nut to hold it in place after adjustment. There will be slack at either end of the rocker which could be measured to determine the amount of clearance. However, the end of the rocker which is operated by the pushrod is frequently concave, so it is difficult to get a feeler gage into the clearance space. Consequently measurement is usually made between the valve stem and the rocker. Since this must be made accessible, it is convenient to put the adjustment screw on that same end of the rocker.

OVERHEAD CAMS

Much of the foregoing applies equally to OHC engines, particularly those with a rocker arm interposed between the cam and the valve. Figures 13 and 14 show two such arrangements as used on Hondas.

Figure 13 makes use of a single overhead camshaft. Each cam operates a rocker arm as shown, and the lash adjusters are threaded screws at the end of the rockers.

Figure 14 is technically more interesting. It shows two overhead cams, each operating a rocker arm or cam follower, which in turn operates the valve. Even though the cam is on the same side of the rocker as the valve, the formula for rocker-arm ratio is the same. Basically, it is simply the distance from pivot to valve stem divided by the distance from where the cam engages the rocker arm back to the rocker pivot. As you can see, the rocker-arm ratio will change considerably depending on the position of the cam, however this is of no concern as long as the designer was concerned about it.

The valve is held closed by a torsion arm, connected to a torsion rod. The arm presses upward against

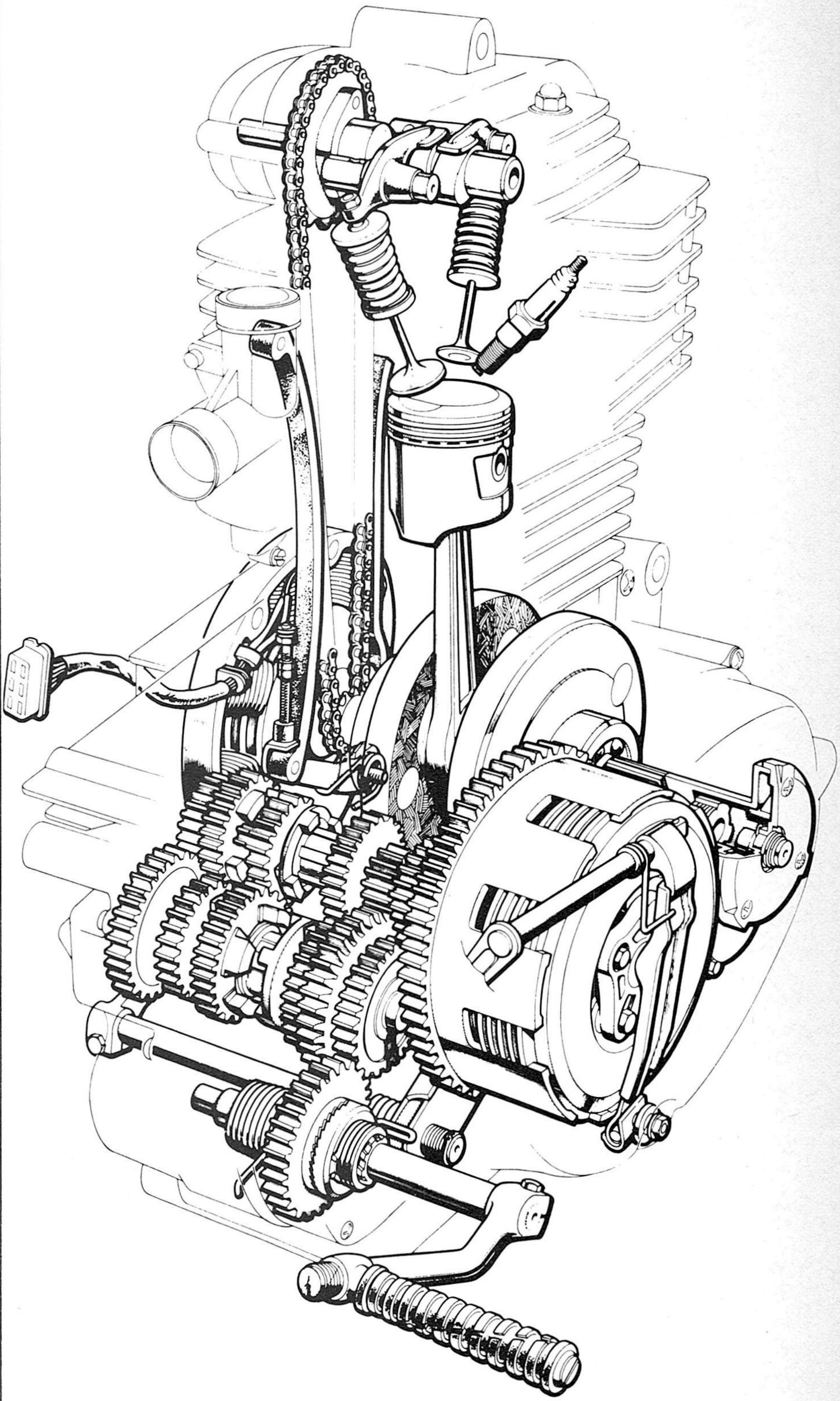


Figure 13—This chain-driven single overhead cam arrangement is used on some models of Honda motorcycles. Conventional coil springs hold the valves closed. Valve-lash adjustment is by the screws on the valve end of the rocker arms.

a collar mounted on the valve stem.

The valve-lash adjustment is at the pivoted end of the cam follower as shown in Figure 15. The cam-follower shaft has an eccentric on it so that, by rotating the eccentric, the pivoted end of the follower is raised or lowered. The entire cam follower will also be moved to the left or right when the eccentric is rotated as shown in Figure 16. This means that Honda is not worrying much about having the contact point *exactly* on the centerline of the valve stem at 50% lift.

This is the kind of design which delights the engineer but saddens the cost accountant. Instead of the more conventional screw and locknut on the end of the rocker arm there is that eccentric shaft for lash adjustment. The design does not even save the cost of the locknut—it's on the end of the shaft.

The torsion-bar valve spring is shown in Figure 17. Torsion bars are expensive to manufacture, starting with the raw material which must be high-quality steel. The center part of the bar must be carefully finished and polished, the ends have to be of larger diameter and each must have a spline machined on it. Honda was even thoughtful enough to leave out one of the splines on each end so the thing cannot be installed with incorrect tension. Additionally, the torsion bar is mounted inside an outer cover which is in two parts, with an inside spline at the end of each part. The torsion arm connects to one half of the cover and the other half is attached to the engine. Finally, the torsion arm is a casting, attached to the torsion bar cover with yet another set of splines and with a slot machined into the opposite end.

All of these precision-made parts are used instead of about fifty cents worth of coil spring and retainer. But it sure is a handsome design! You can admire it all together in Figure 18.

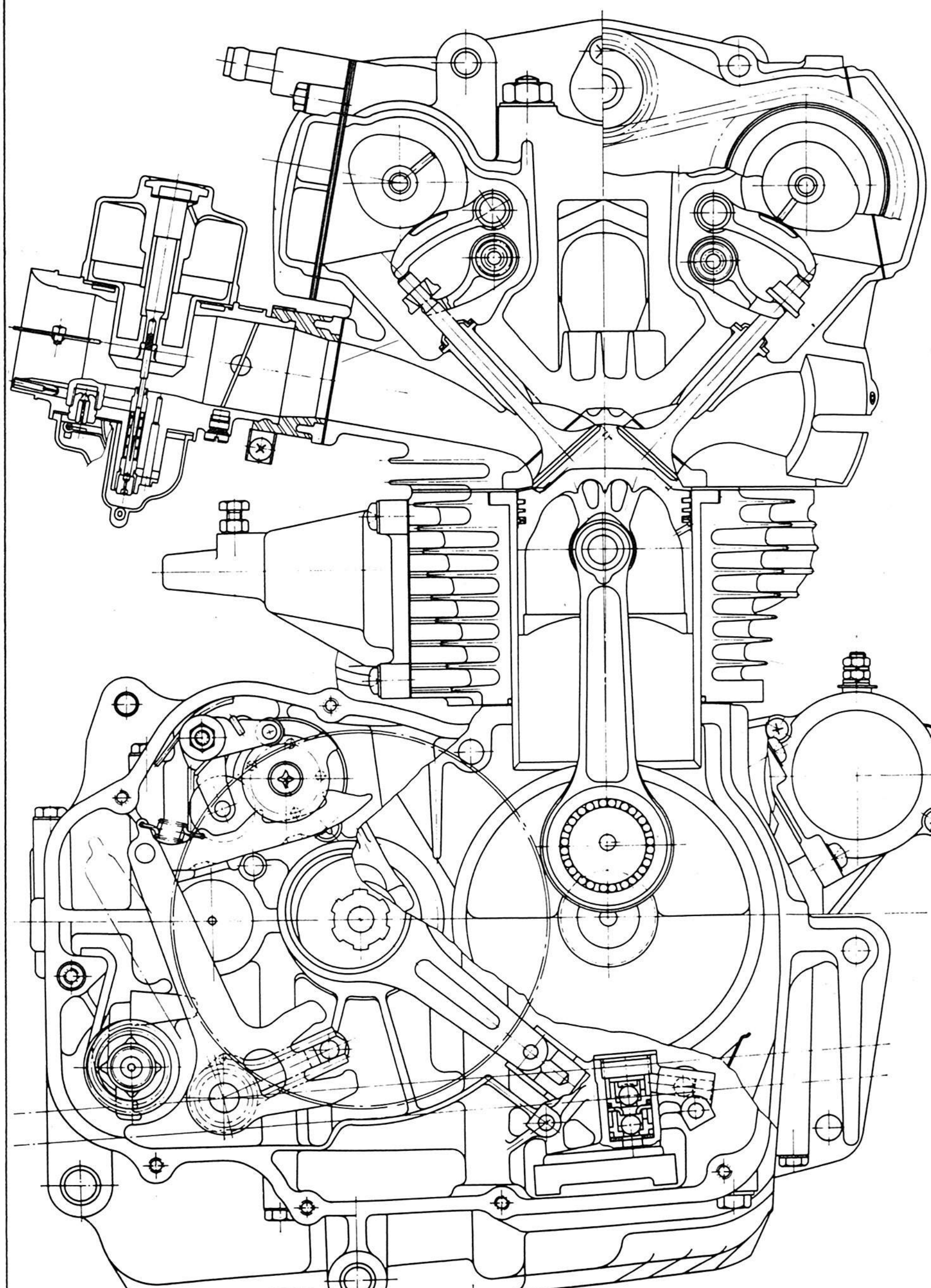


Figure 14—This sophisticated design, used on the Honda 450, has torsion bars for valve springs and an eccentric cam-follower shaft for lash adjustment.

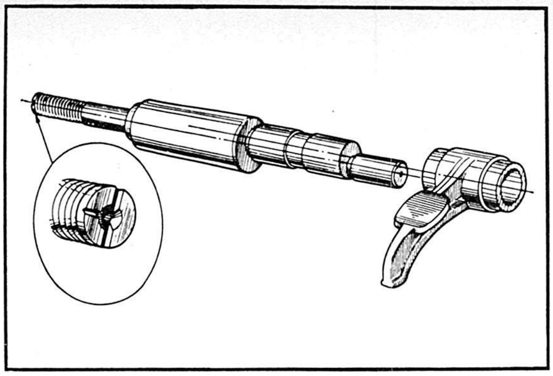


Figure 15—Valve clearance is set on the Honda 450 by rotating this shaft. The eccentric moves the pivoted end of the follower up or down as needed to set valve lash.

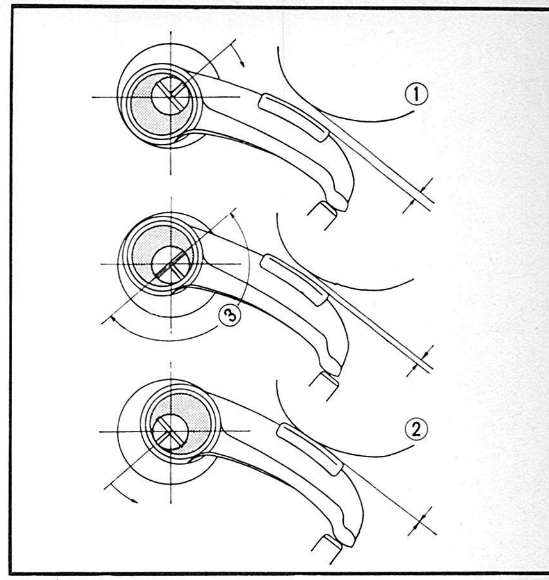


Figure 16—The eccentric adjustment also moves the contact point on the valve stem as shown in this drawing. At 1, valve clearance is maximum; at 2 it is minimum. The range of adjustment of the eccentric is 180 degrees, shown at 3. Clearance is set by measuring the gap between the pad on the cam follower and the cam.

Figure 17—The torsion-bar valve spring used on the 450 Honda is a neat solution to the problem of valve spring surge which is common among coil-type springs. Surging is waves of motion rippling up and down a coil spring, independent of the normal compression and expansion due to valve action. The intrinsic mechanical friction within the torsion bar aids in damping out surges.

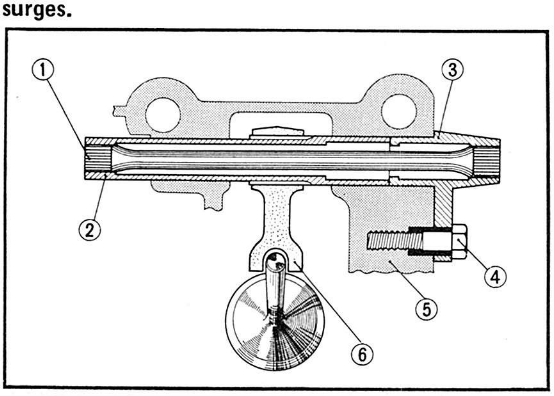
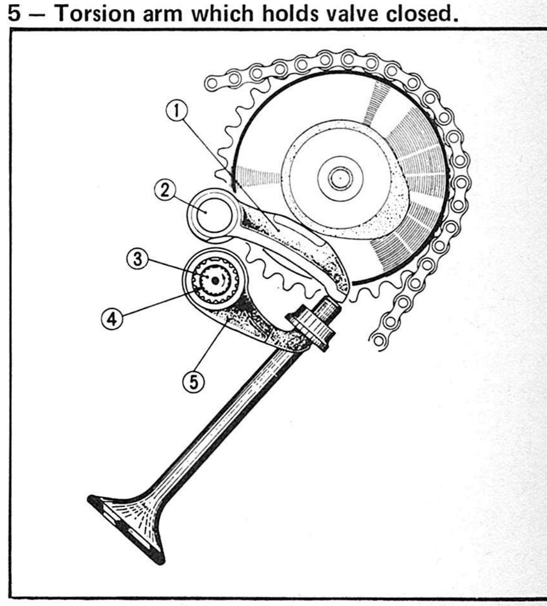


Figure 18—Close-up of the Honda 450 valve arrangement:
1 — Cam follower.
2 — Cam follower eccentric shaft.
3 — Torsion-bar valve spring.
4 — Torsion-bar outer cover.
5 — Torsion arm which holds valve closed.



Honda did not use this arrangement on the later four-cylinder engines, indicating possibly that the bean counters won the argument.

With any kind of an OHC arrangement, compression can be increased by milling the head, the top or bottom of the barrel, without altering the geometric relationships among the parts on the head itself. However, the distance between camshaft and crankshaft will be reduced and this must be considered.

If the OHC is driven by a shaft with bevel gears, the shaft will now be too long. Sometimes these shafts contain a tongue-and-groove coupler along their length, which can be modified to shorten them.

If the camshaft is driven by a roller chain, as shown in Figure 13, reducing the distance effectively puts slack in both sides of the chain path. The crankshaft will take up slack on one side, to drive the cam, and thus all of the additional chain slack will appear on the normally-slack side to be taken up by a chain tensioner.

The engine modifier should check to be sure that the tensioner has enough range of travel to accommodate this extra length and does not become overextended in the process. Because the crankshaft effectively rotates a bit to take up the additional chain slack before the camshaft starts to rotate, the timing of all events upstairs in the camshaft department will be slightly later in respect to the rotation of the crank. This may not be significant, but should be considered.

A simple chain tensioner is shown back in Figure 13. It is a leaf spring bent so as to push against the chain. To take up slack, you bend the spring a little more using the screw adjuster at the lower end. A more sophisticated tensioner is shown in Figure 19.

Figures 13 through 19, and Figure 21, are used here through the courtesy of American Honda.

DIRECT ATTACK

There are OHC engines which do not use a rocker arm or cam follower. These engines still generally put an intermediate part between the cam and the valve stem, basically to provide a larger rubbing area for the cam surface than would be provided by the relatively small stem of the valve. Typically this intermediary is in

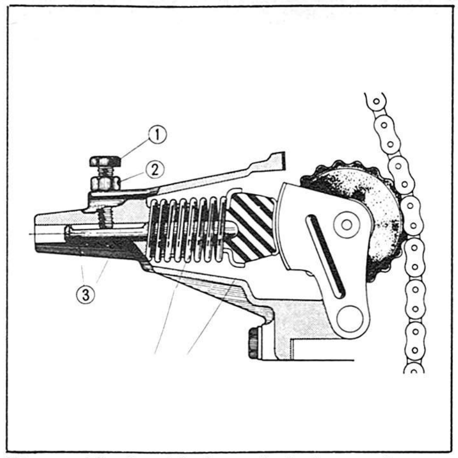
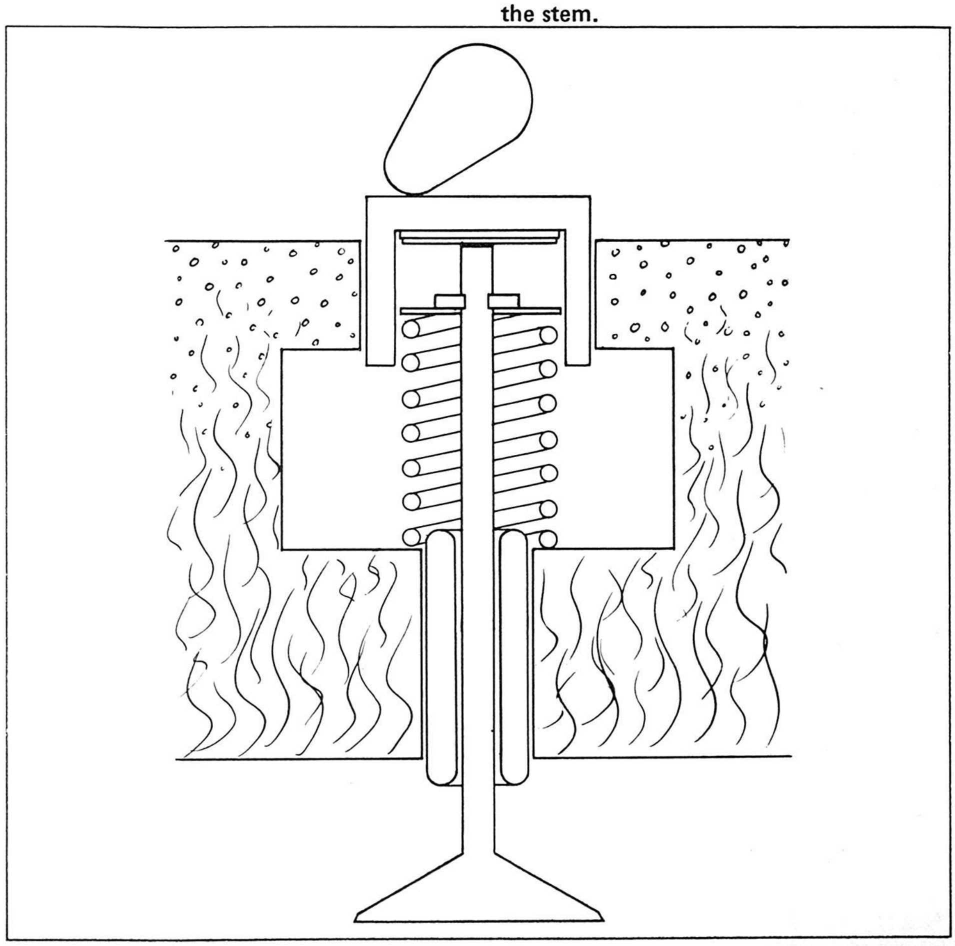


Figure 19—Sophisticated chain tensioner design by Honda. To adjust tension you loosen the locking screw 1 to allow the coil spring to force the roller into the chain path and retighten the locking screw. This clamps push bar 3 which holds the adjustment until the next time you allow it to set itself by releasing the push bar. The spring is designed to put just the right amount of tension into the chain path. Compare this to the unsophisticated bent leaf-spring tensioner shown in Figure 13.

Figure 20—Direct actuation of the valve by the cam. Without the mechanical advantage of a rocker arm, all of the lift must be on the cam. The inverted "bucket" between cam and valve stem provides a larger rubbing area for the cam and protects the valve stem from side loadings due to the rubbing action of the cam lobe. Lash adjustment is by spacers between the bucket and the stem.



the shape of an inverted bucket which fits over the stem of the valve, as shown in Figure 20. If the bucket is arranged to travel in a separate bore, then that relatively large-diameter bore will take all of the side loads imposed by the sliding motion of the cam across the face of the bucket. With arrangements such as this, valve clearance can be adjusted by shims or spacers between the bucket and the valve stem.

AIR FLOW IMPROVEMENTS

If you are going for the hot cam with more lift, more duration, and all that, you will naturally start thinking about port and head work to improve the air flow.

It's easy to think of port work on two-strokes and four-strokes as about the same kind of job. Which they are definitely not.

The usual way to change port timing on a piston-controlled two-stroke is to change the dimensions of the ports and the skirt of the piston. If ports are altered, it is obviously desirable to blend the shapes of the passages into the new shapes of the ports, so two-stroke tuners make much use of grinders. When the two-stroker wants more air flow in, and a larger carburetor to go with it, he thinks little about enlarging the air passage from the carb into the engine. This is routinely done by unskilled labor. However the inlet passage only dumps into the crankcase.

The critical gas-flow area in any engine is into and out of the combustion space because this affects getting new mixture in, exhaust out, scavenging the residual exhaust, and the swirl or turbulence of the mixture in the chamber during combustion. Most good advice on hopping up a two-stroke says "Leave the transfer ports alone!" Think on that a minute.

Now, if we return our attention to the four-stroke, valve timing is accomplished by the cam. The main obstruction to gas flow in and out is the valves themselves and to reduce that obstruction we can use a cam with higher lift.

What's left for the air passages in the head to do? The complex job of getting mixture in and out, scavenging, turbulence, and sometimes directing the mixture into the cylinder in such a way that it is not aimed straight at the exit on the opposite side. The velocity of the incoming charge is important. Make the hole larger and the reduced velocity may do things the man-from-grinder didn't expect. Same with the exhaust.

Of course you can match up ports, polish and smooth. If you know what you are doing you can open up the passages and install larger valves. But air flow is a tricky business and the really good work is done by experts using air-measuring instruments including tiny probes which they stick into the passages to find out what is really happening.

INCREASING COMPRESSION

Earlier I mentioned that one improvement you can make to any engine with no penalty in performance at any RPM is to make it stock or, if you prefer, "blueprint" it.

Another improvement with this *potential* is to increase the compression ratio—PROVIDED you don't get into pre-ignition or detonation. If you avoid these problems it makes the engine run better at all RPM although it may shorten the time between overhauls because more power means more wear.

As you know, the quality of available gasoline in terms of anti-knock rating is steadily going down because car engines are going down in compression ratio to reduce emissions. If you choose to buck this trend, be sure about it before you start.

To increase the compression ratio, basically what you want to do is reduce the volume above the piston when it is at TDC. This can be done in several ways. One is to change the shape of the combustion space in the head by filling it up with metal and machining it out again to provide smaller volume. Another is to buy a custom-made high-compression head if one is available for your engine.

For some engines there are high-compression pistons which simply project farther into the combustion space because the top is raised up or domed in some way. If the piston doesn't cave in or otherwise fail due to the higher pressure, you've got a quick slick trick. But the bump on the top of the piston can affect breathing if the piston designer didn't have his head on straight.

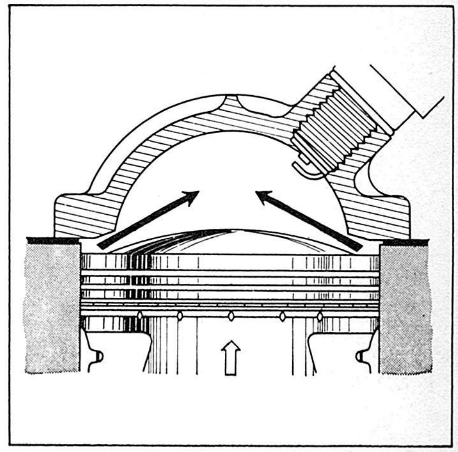
If you can't bring the piston closer to the head, you can bring the head closer to the piston. You can remove metal from the bottom of the head, the top of the barrel, or the bottom of the barrel, depending on which is appropriate for a particular engine. We have already seen some of the minor complications which result from doing that on pushrod and OHC engines.

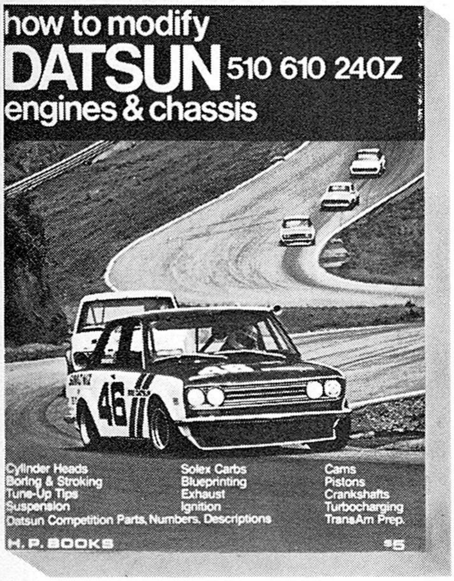
A remaining complication, which can occur in any engine, is that the clearance between piston and head is reduced enough so the piston strikes the head. This merry tinkle results in a soon trip to the parts place. An engine may not do this when cranked over or run at low RPM but it may destroy itself at high RPM because the accelerative forces on the piston and rod are much greater. As the piston is skidding to a stop at TDC, the con rod stretches a little and, Bang!

Since hearing it happen is finding out about it the hard way, it is best to measure the piston-to-head clearance and be sure there is enough. No part of the top of the piston should get closer than 30 or 40 thousandths to any part of the head. Typically the problem is with the squish band around the perimeter of the combustion space, as shown in Figure 21. You avoid the problem if you follow the procedure outlined by Wayne Ebaugh in a later section of this book.

On a four-stroke, you not only have to worry about squish band, you also have to

Figure 21—Small clearance between piston and head, at sides of bore, is called squish band. Purpose is to squish mixture out of that space and get it swirled into flame front of combustion. This reduces chance of distant pockets of mixture detonating before flame front can reach them. The large amount of metal in contact with the mixture at the periphery of the bore tends to keep that mixture cooler which also reduces chance of detonation.





worry about the piston crashing into the valves. The critical time is at TDC on the exhaust stroke when, due to overlap, both valves are open some amount and the piston is traversing TDC.

To measure these clearances, you can put a wad of clay or some such on top of the piston, bolt on the head, crank the engine over once, take the head off and measure the thickness of the clay where it was smashed by something. Between the piston and the nearest part of any valve, you want to assure about 0.1 inch. The reason this clearance must be greater than piston-to-head clearance is that the valves can also stretch due to high RPM inertia loadings and grow longer with temperature.

A better way to measure valve-to-piston clearance is to rig up a dial indicator on an assembled engine, except with some lightweight springs holding the valves closed. Rotate the engine carefully while occasionally pressing the valve down farther than the cam has placed it. When the piston approaches TDC, you should be able to touch the piston by pushing down the valve and the dial indicator will tell you how much clearance there is. If there isn't enough clearance due to milling, a high lift cam, trick pistons, stroker crank, or whatever your little trick was, then you face the problem of cutting away metal on the top of the piston to make some clearance. An excellent and thoroughly practical discussion of these and related matters is in the camshaft and valve train chapter written by Racer Brown for the H. P. Book entitled *How To Modify Datsun Engines & Chassis: 510, 610 & 240Z.* The material gives motorcyclists a look into the future because, as you will see, Racer Brown has to consider exhaust emissions right along with engine modifications because the long arm of the law may at any time stick an emission measuring device into the tailpipe of an automobile. It seems likely that motorcyclists will face the same problem soon and also the problem of using low-octane non-leaded pump gas. Besides that, I think Racer Brown says it in an entertaining way.

Here is a small sampling of Racer Brown on camshafts:

SELECTING THE CAMSHAFT

Now for camshaft selection. Clear your mind of all romance, hogwash, myths, old wives' tales, phase of the moon, etc. You want a camshaft that *works* for your application, regardless of the degrees duration and/or overlap, valve lift, or whatever. It was stated earlier that small-displacement engines need all the torque they can get, particularly at lower engine speeds, and if this is a factor, long duration, very high lift camshafts are O-U-T. They're great for strictly race engines. But for a street-driven vehicle, they'd need a road map to fall out of a tree . . . and probably a push to get them started.

Street—Let's begin with a street application, basically a stock engine, where idle characteristics, throttle response, general drivability and exhaust emission levels are all contributing factors. Duration should be in the low to mid-240° range with no more than about 25° overlap. Datsun cammer engines respond very nicely to valve lift; it actually helps low- and mid-range torque, as well as maximum power. But for this application, lift should be in the 0.430 to 0.450-inch range. A couple of years ago we proved two points: (1) performance level could be improved and (2) emission levels reduced with nothing more than a mild camshaft. Average road performance level in the 2,800–6,500 RPM range was improved by 7+% with a maximum of 10+% at the higher engine speeds. Average exhaust emissions of unburned hydrocarbons, carbon monoxide and oxides of nitrogen were reduced by approximately similar percentages. The vehicle was an otherwise bone-stock 1971 Z-car with about 25,000 miles on the clock. A few carburetion modifications were indicated to help emission reductions even more but the primary objective was to learn what the camshaft-only change would accomplish. An incidental advantage was that fuel economy was increased by about 4%, all of which showed that the thermal efficiency was better than stock. The camshaft had 250° effective duration with 0.440-inch lift.

With the lower compression ratios of the later Datsun engines, camshafts for strictly street applications must be very mild indeed. The drop in compression ratio means a loss in cylinder pressure, which is contrary to improved performance. The game plan here is to capture as much cylinder pressure as possible, yet retain normal combustion with pump-type fuels having very small amounts of tetraethyl lead, or none at all. This suggests very short duration camshafts in the mid-230° range with from 14°–18° overlap. In 1972 and later engines, a camshaft like this by itself will usually wake up an engine to match the performance level of earlier stock engines with higher compression ratios. In most cases, such a camshaft can use all stock Datsun pieces, with the exception of valve lash pads, so long as maximum engine speed is kept within the 6,000-6,400 range.

The next step up for the fours is for someone who is willing to bolt an extra stock two-throat progressive Hitachi carburetor onto a good aftermarket intake manifold, and still keep within existing exhaust emission limits for the year of vehicle concerned. Unfortunately, no such manifolds existed as this book went to press. In this case, a higher performance level can be expected, as well as higher average engine speeds. A camshaft for such an application should have an effective duration in the high-240° to low 250° range and from 34°–38° overlap. For the privileges of higher power output in conjunction with considerably improved performance, and the realization that this guy will usually have his foot buried a bit deeper in the carburetors when the occasion permits, a higher price must be paid, but not necessarily all in dollars or yen. A rougher and perhaps a

faster idle and not much muscle below about 2,800–3,000 can be expected. The rougher idle brings with it less manifold vacuum at idle and the lower engine speeds, which can adversely affect the power braking system. So if you lean on the throttle harder, you can lean on the brake pedal harder. A camshaft assembly of this type will usually include special valve springs, spring retainers and lash pads that will permit a 7,000-plus maximum safe engine speed.

It should be pointed out that the standard Datsun four-speed gearbox is not equipped with ideal (whatever that is) intermediate ratios. The first-to-second spread is OK, as is the third to fourth. But the large second-to-third gap is a factor that must influence camshaft selection because after the two-three shift the engine must have enough torque to pull itself out of the hole caused by the two-three gearbox ratio spread.

This is best translated into five simple words: **DO NOT OVERCAM YOUR ENGINE!** If questions arise about the suitability of two or more camshaft profiles, ask these questions of someone qualified to give the best answers related to your particular application. If there is still some indecision, pick the milder camshaft, accept its limitations, and be glad you made the right choice.

OTHER ENGINE MODIFICATIONS

So far, no mention has been made of other engine modifications, and for a purpose. For vehicles that serve as basic point-to-point transportation on freeways and surface streets in areas of high vehicle population, as well as more rural parts of the countryside, efficient and enjoyable vehicle operation pivots about one word: drivability. Along with providing such basic transport at a relatively nominal price, Datsuns are "fun" cars to drive. A *mild* camshaft, perhaps with a more efficient induction system, actually improves drivability. Modifications such as larger valves, large intake and exhaust ports, tricky competition-type exhaust header systems, etc., all have one point in common: Singly or in combination, they seriously inhibit drivability by taking too much torque away from the engine in the most frequently-used engine speed ranges, and simply do not belong in engines caught at stop lights, bumper-to-bumper traffic or short-hopping. Again—either singly or in combination—these modifications will cause poor idle, poor throttle response, poor part-throttle operation, so who needs 'em in a *street*-driven vehicle? You don't if your vehicle fits in this category.

There is one other exception: compression ratio. Higher compression ratios equate to higher thermal efficiency, higher torque and power outputs. However, with the quality of available pump gasolines steadily diminishing, the advisability of raising the compression ratio is questionable, except possibly at higher altitudes, or where one is still blessed with the availability of decent fuels. A higher ratio *does* help, but there is a very fine line indeed between balancing the highest useful compression ratio with valve timing and average fuel quality. This says nothing for the seemingly insignificant details that must combine to make a higher compression ratio function properly such as reasonably constant (and correct) air/fuel mixture ratio (no lean spots under full load), accurate and consistent total spark advance, correct spark plug heat range, adequate fuel delivery system, proper spark advance curve, acceptable engine oil and coolant temperature, and absolutely zero detonation and/or "dieseling" (when you have to beat the engine with a club to make it quit running after the switch is turned off). These are the trivia that will make a relatively high compression ratio engine function as it should, or can break it into more tiny bits than you'd care to count. For a strictly street engine, the small increase in compression ratio that could be tolerated probably isn't worth the effort.

Most of us who own motorcycles use them as toys—whether we admit it or not. Just like the guy with the speedboat, sailplane, or a pair of skis.

Because we are fond of them, enjoy them a lot, and play with them on weekends, the idea of making them better turns out to be almost irresistible. It also offers us another game to play with our toys.

For the average person, better seems automatically to mean only one thing: **more power.** Off he goes, lusting for power and willing to spend large amounts of money and time to get it.

Every experienced tuner and every owner who has been the route, whether it is with cars, bikes, or pogo sticks, will tell the first-timer not to over-modify. And then shake his head sadly as the recipient of that good advice proceeds to ignore it.

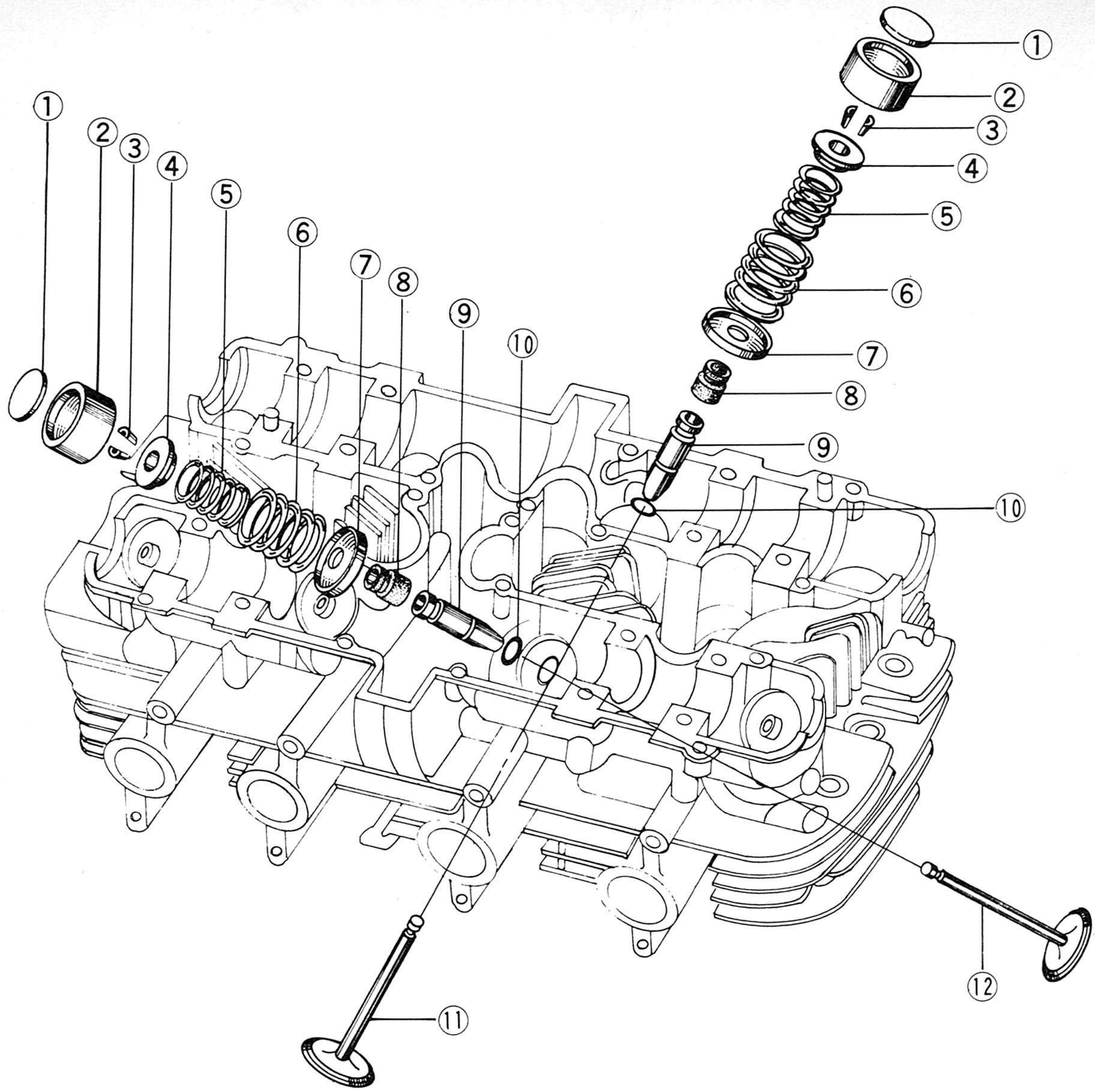
There are three guest contributors to this part of the book and they all hammer away at the same theme. Don't over-modify.

I have only one thing to add to that. Don't *over*-modify.

Weekend Warriors—Enter the "Weekend Warrior." He has one vehicle and a strong desire to compete in motorsports events. These could be slaloms, gymkhanas, rallies, road races, drag races, hill climbs, etc. He knows a bone-stock engine hasn't a prayer of being competitive in any type of off-road event where modifications are permitted. He also knows that he must sacrifice some drivability and loss of operating economy on the street in order to be reasonably competitive in the off-road event of his choice. And he is willing to accept these sacrifices—up to a point. But where is that point?

A good question and a difficult one, and one compounded by increasingly stringent exhaust-emission limits. He may be called upon at any time for a roadside emissions check by state or city authorities, a practice that is not only entirely legal but one which is increasing in frequency all over the U.S. It's a very safe bet that if his engine is modified to the point of being marginally streetable, any exhaust "sniffer" will turn thumbs-down on the exhaust emission levels. Then he had best be prepared to convert the engine to stock condition and submit his vehicle for a recheck, or face the consequences and penalties of the law.

The best advice is to keep all emission control devices hooked up and operative when the vehicle is driven on any public road. These devices *do* help reduce exhaust emissions and if nothing else, they give tangible evidence to any vehicle inspection officer that the guy's implied intent was conformity with the law, even if the exhaust emission levels are unacceptable. Guy: "I've been thrashin' it pretty hard lately. Guess it needs a sharp tune-up." Inspection official: "Yeah. Sign your citation here, and *do* visit our humble in-



1 Shim
2 Valve lifter
3 Split keeper
4 Valve spring retainer
5 Inner valve spring
6 Outer valve spring
7 Valve spring seat
8 Oil seal
9 Valve guide
10 Circlip
11 Exhaust valve
12 Inlet valve

Drawing of the head and valves of a double-overhead-cam four-stroke four-cylinder engine. Except for the cooling fins and the fact that I already told you, you might not know that this is a motorcycle engine. It's the impressive Kawasaki Z, 900cc, 82 horsepower at 8,500 RPM. Courtesy of Kawasaki.

What's it doing in the middle of Racer Brown's discussion of Datsun cams and valves? Read Racer's description of valve duration, lift, compression and such for a good-performing engine and then compare:

Kawasaki valve duration is 280 degrees. Overlap is 60 degrees. Compression ratio is 8.5 to 1. Valves are operated with bucket-type valve lifters and clearance is set by shims (on top), etc., etc.

A multicylinder bike engine is not that much different from a multicylinder car engine. However, I thought you would rather look at drawings and pictures of motorcycle parts.

spection station again. Within the mandatory 30-day period, of course. And with the emission levels *right*." Sound ridiculous? Perhaps. But it's happening every day!

The problem is further complicated by trying to explain to some aspiring John Morton or Bob Sharp that he has to use his Datsun as a transportation hack for six days a week to compete in an off-road event on the seventh day. This very strongly suggests conservatism for any and all internal/external engine modifications. In the area of camshafts for such applications, effective duration should be in the low- to mid-260° range with about 44°–48° overlap. A camshaft assembly must include special valve springs, spring retainers and lash pads of the correct thickness. Usually, this type of camshaft will have a maximum safe engine speed of around 7,500, but it may require notching the pistons for the required piston-to-valve clearance.

Before we depart for more exotic worlds, a few more words about exhaust emissions. It has been conclusively proved that a relatively mild camshaft can do two things in Datsun engines: It can improve road performance and reduce exhaust emissions at the same time. Similarly, a good aftermarket intake manifold could do good things in both areas by a vast improvement in cylinder-to-cylinder air/fuel mixture distribution and by maintaining relatively high mixture velocities throughout the entire induction system. A mildly but expertly modified cylinder head has proved beneficial in both areas but it does more for performance than it does for exhaust emissions. With these mods, a slight increase in compression ratio becomes feasible. Don't get carried away: A good, honest, genuine measured 9 to 9.5 to 1 should be considered adequate because the extra heat generated by higher compression ratios increases oxides of nitrogen (NO_X) emissions. Then come the little things that count such as correct carburetor calibration, correct and stabilized ignition advance curve, perhaps a breakerless magnetic-impulse ignition system, a good set of wire-type radio-shielded secondary spark plug and coil cables, and so on. Each item individually will improve performance and most of them will reduce exhaust emission levels, while the remaining few will at least not be detrimental to exhaust emissions.

So what have we got? With all of the preceding done with precision and moderation, we have a *combination*; an engine assembly capable of producing a very good level of performance, again in the most frequently-used engine-speed ranges . . . without extremes in any direction. We also have a more efficient engine assembly, one which utilizes the air and fuel within the cylinders more effectively, and therefore one which at least has the potential of reducing exhaust emissions significantly. Whether it does or not is up to the individual more than it is to judiciously-applied and moderate modifications.

Race Engines—Now let's go on to fully-modified Datsun cammer race engines. Generally, these engines are quite sensitive to just about any intelligent modification and respond in a most gratifying manner. This doesn't mean "biggest" or "most" is always best in any single component or combination. Again, the strictly competition engine that is most successful in a given application must necessarily be compromised in one or more areas.

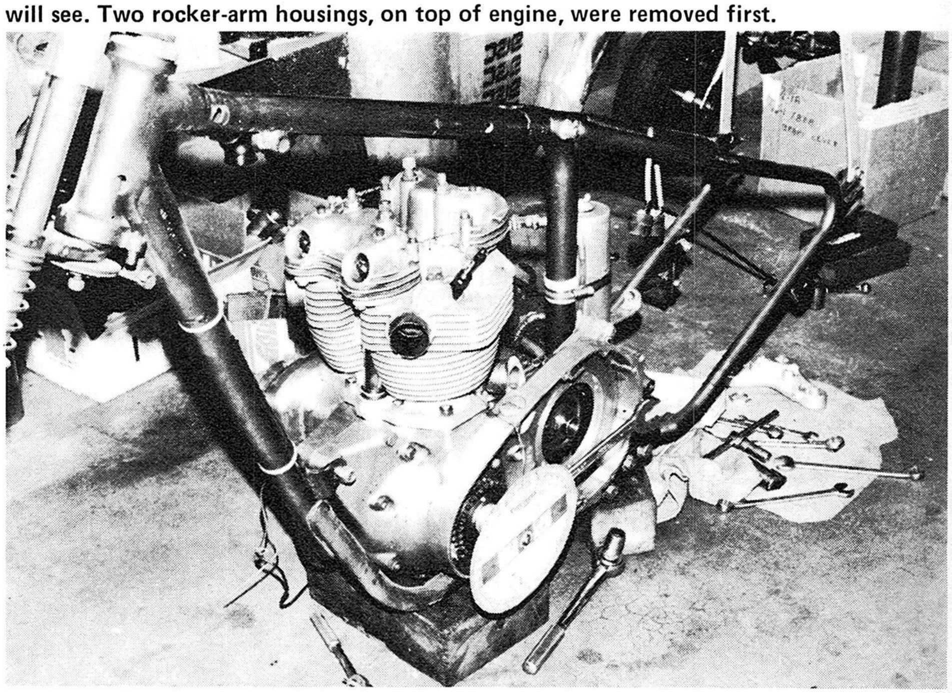
If mid-range and upper mid-range output is a major factor, effective duration should be kept in the high-280° to mid-290° range with from 70°–75° overlap. Valve lift should be in the 0.580 to 0.610-inch range. If otherwise rightly equipped, such an engine will be strong from about 4,800 on up to about 8,000.

If a maximum-effort engine seems to be the correct plan, and the vehicle is properly geared so that minimum engine speed doesn't drop below about 6,000, then the sky's (almost) the limit. In this case, effective duration should be in the 310°–320+° range with from 0.620 to 0.650-inch valve lift. With such a camshaft, the best effective engine speed range would normally be from about 5,800 to 6,000 through at least 8,800.

PISTONS AFFECT BREATHING, ETC.

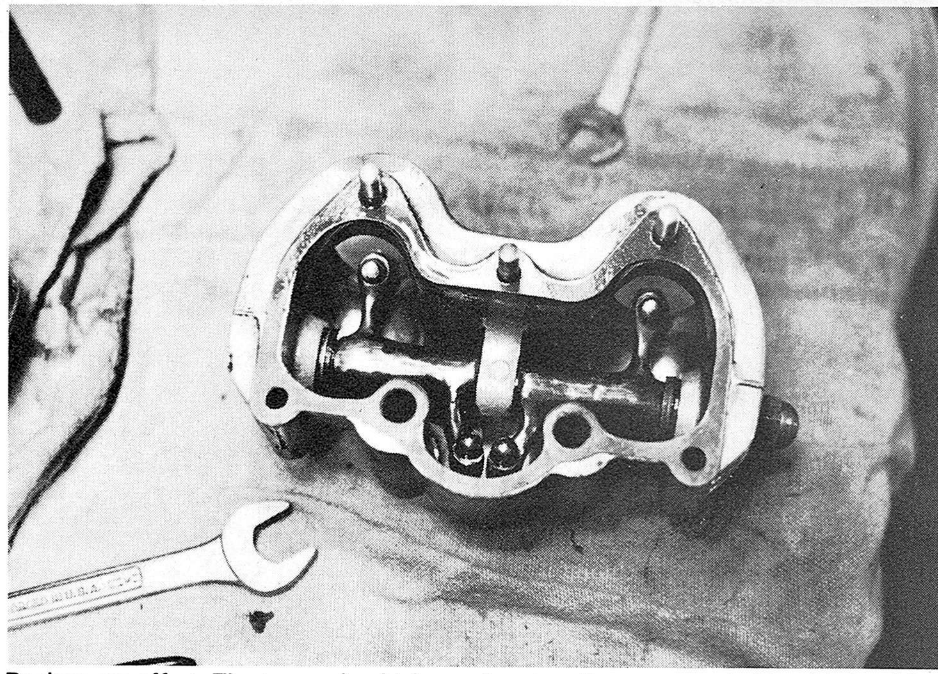
The design criteria for an acceptable piston, aside from a good stiffness-to-mass ratio, proper skirt design to prevent skirt collapse, good piston ring placement, minimum piston pin exposure between the pin bosses in the piston, etc., should be: (1) Acceptable compression ratio, but *without* a high piston crown resembling a misplaced Alp. (2) Adequate space around the spark plug to give a good strong point for combustion propagation. (3) More-than-adequate crown thickness in the area of the valve reliefs, so that the valve reliefs can be made not only deeper but with radii somewhat larger than the valves, and without weakening the hot-

Phil York's 650cc special-framed Triumph which he runs on fuel at drags and Bonneville. The following series of pictures were taken at random one evening while Phil was replacing pistons and rings. Engine is a push-rod OHV twin-cylinder four-stroke, as you will see. Two rocker-arm housings, on top of engine, were removed first.



strength of the piston structure. (4) A piston designer with brains enough to recognize the importance of the fact that the air/fuel mixture and/or exhaust gases simply DO NOT and will not flow properly around sharp edges and corners. Perhaps as a very minor minority of one, I would like to see a piston in which the intake and exhaust valve reliefs are joined together to form a single "trough" type valve relief, similar to the original-equipment Chevrolet 302 Z-28 piston.

Items 2, 3 and 4 are essential for proper cylinder breathing, particularly during the valve overlap period, and particularly at extremely high engine speeds, say above about 8,500 on up. However, these items are contrary to Item 1, acceptable compression ratio. Nearly everyone has heard of some ridiculously high compression ratio numbers bandied about for these engines, but I can assure you that it is extremely difficult indeed to get an honest, genuine, measured compression ratio of over 12 to 1, *without* shrouding the valves, the spark plug, or both, and still keep the power curve relatively flat above about 8,500. Again, this refers to the "open" L-24 type combustion chamber with valve unshrouding modifications, but it also applies to similarly modified optional L-16, L-18 large-valve heads. If the engine is going to run well and produce very good power in the 8,500-plus-RPM range, it *must* have breathing room to do so, even if it means a *sacrifice* in compression ratio.



Rockers are offset. The two ends which are close together are operated by side-by-side push rods from crankcase. Opposite end of each rocker operates valves. One of these rocker assemblies operates both intake valves, the other operates both exhaust valves.

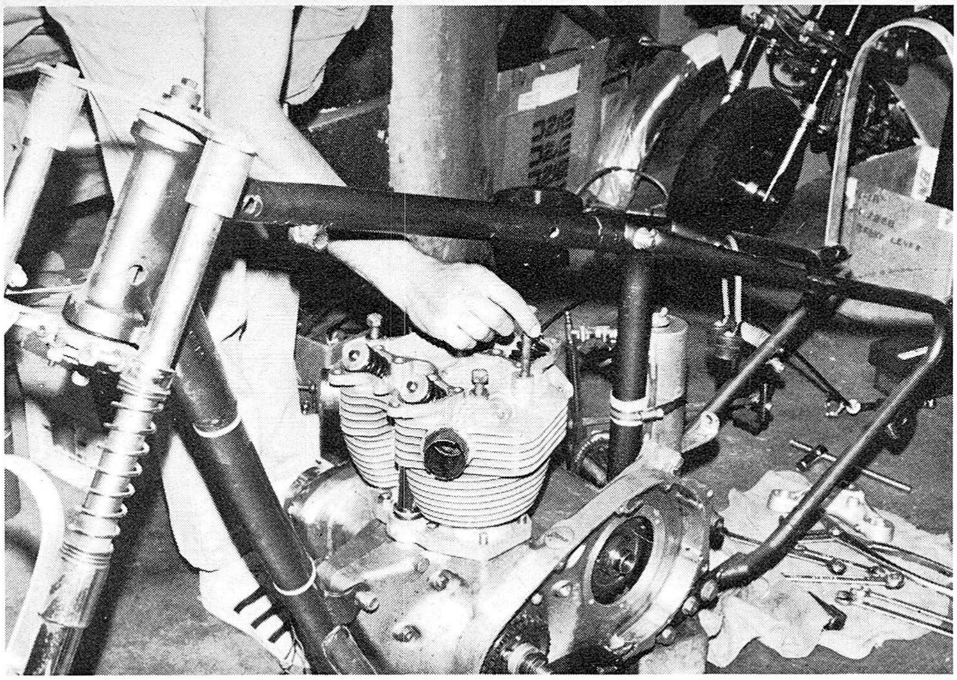
PISTON-TO-VALVE CLEARANCE

Lots of piston-to-valve clearance does more than allow the engine to breathe well at extreme engine speeds. It also provides the engine with a "cushion" of space in the event of a missed shift or broken driveline component when the engine speed would tend to go completely out of sight, and thus minimizes any engine overspeed damage. It also permits the camshaft to be advanced or retarded to suit conditions of the moment.

We normally recommend a minimum piston-to-valve clearance of at least 0.090-inch between the piston and the intake valve at their closest point, and at least 0.100-inch—and preferably more—between the piston and the exhaust valve when the piston-to-valve clearance is measured by rotating the engine by hand. In an operating engine at full blat, these numbers are usually reduced by about half because the crankshaft bends, the connecting rods stretch, the piston pins bend and the pistons stretch, and it all happens just before and after top center when the pistons change direction, the least opportune period for maintaining adequate piston-to-valve clearance. The condition is made worse during a closed-throttle downshift, or similar circumstance when the cylinder (usually a pressure vessel) is changed into a vacuum vessel by the closed throttle, at which time the high vacuum in the cylinder tends to draw the pistons and valves together more closely than when the engine is under load.

The reason why additional piston-to-exhaust valve clearance is called for is because *any* camshaft drive tends to permit the camshaft to retard itself in relation to the crankshaft, thereby bringing the exhaust valve closer to the piston. This is particularly true with a chain-driven camshaft because as engine speed increases, centrifugal force acting upon the chain pushes the chain away from the sprockets and the chain rollers contact the sprockets increasingly closer to the outer edges of the sprocket teeth, and all the while the camshaft is resisting rotation due to friction, valve-spring loading, etc. Chain stretch compounds the problem. It is a function of the load applied to the chain and of course the number of links in the chain. Datsun chains are quite long, about 42 inches in circumference, with 110 links, which means that keeping the valve timing exactly right at all times is nearly impossible. It is therefore better to start out with a slightly advanced camshaft—say by 3 or 4 crankshaft degrees—because there is no way in the world that it can be kept from retarding itself as the engine is run, particularly at high engine speeds. This is also the reason for the three different timing marks and three different dowel pin holes in the Datsun camshaft sprocket; they make provision for advancing the camshaft in four-crankshaft-degree increments, but they make no provision for retarding the camshaft. *It does that by itself with no outside help required!*

A high dome, high compression ratio piston that shrouds the valves and the flame front isn't all bad; it really wakes up the low and mid-range torque, but don't expect the engine to have good breath control at 9,000 RPM.



After rocker assemblies are removed, valve stems with springs and keepers are visible. Phil is taking off the head.

It won't!

Naturally, any increase in cylinder bore diameter and/or crankshaft stroke will raise the compression ratio with a given combustion chamber cavity volume.

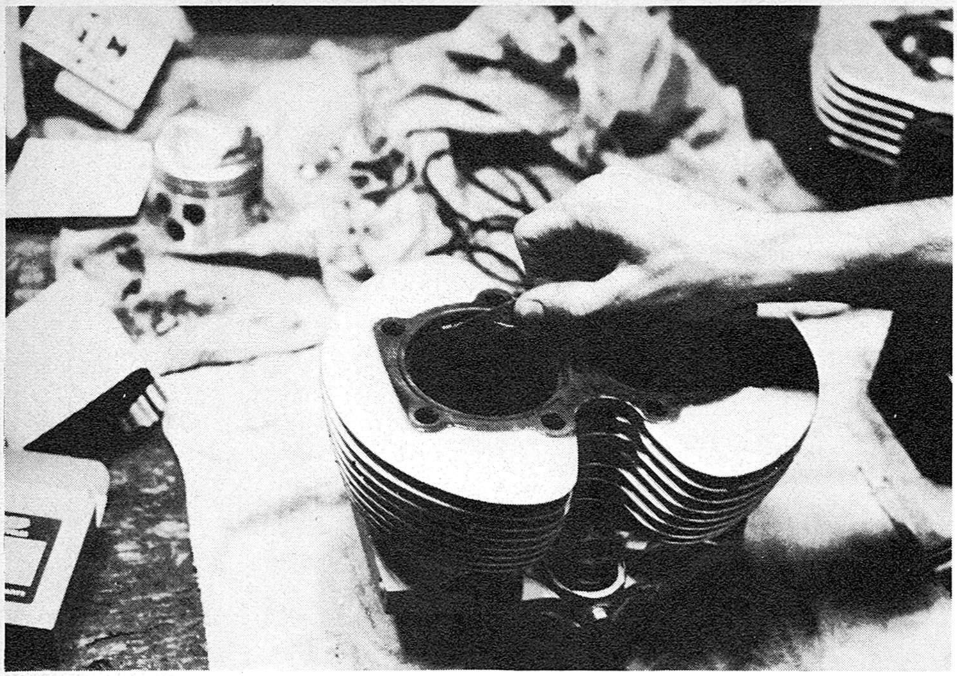
Obviously, the cylinder head can be milled to gain compression ratio, but with the Datsun engines, there are some not-so-obvious factors involved. Milling from 0.060 to 0.070-inch is considered a "safe maximum," and then there may be head gasket sealing problems. If there are sealing problems, the cylinder head should be O-ringed with 0.030 to 0.040-inch diameter soft copper armature wire or soft stainless steel wire, leaving about 0.010 to 0.012-inch of the wire exposed from the cylinder head face to give the required seal around the cylinder bores. O-ringing the cylinder block is not recommended unless the final cylinder bore honing operation is done with a honing plate, cylinder head gasket and O-rings installed and torqued down. If this is not done with O-rings in the block, the O-rings will cause the tops of the cylinder bores to shrink about 0.002 to 0.003-inch on the bore diameter, and will affect cylinder bore diameter for about an inch down from the block face when the cylinder head is bolted to the block. We really don't need sticking pistons.

When a Datsun cylinder head is milled, one and possibly two other items must be put right. With the camshaft in the cylinder head and the head milled, the center-to-center distance between the crankshaft and the camshaft is shortened, which means there is extra "slop" in the camshaft drive chain. To correct this condition, the chain guide must be moved.

PORTING

If, due to the application, modifications to the intake ports and pockets, exhaust ports and pockets, valves, combustion chambers, etc., are indicated as they usually are even in engines with milder states of tune, it is highly recommended that the cylinder head and valves be sent to a cylinder head expert equipped with an air flow bench and the intelligence to use it correctly. Port, valve and combustion chamber design, to say nothing of induction and exhaust systems, have become extremely sophisticated within recent years, and nothing can kill a cylinder head quicker and deader than gouging it out in the wrong place by someone who may have the best intentions in the world, but who lacks the know-how, experience and air flow measuring equipment, all of which are required these days to do the job correctly. So go to an expert in the first place and save yourself the cost and frustration of having to do the job again after it has been bungled. Be very explicit in telling him your exact requirements for the engine and let him decide what is appropriate in the area of valve and port sizes, etc. The same expert will usually be equipped to equalize the volumes of the combustion chamber cavities in the head. All this may not be cheap but it will be cheaper than having to do the job twice in order to get it done once, and right. If the guy is sharp and knows his Datsuns, it probably won't be necessary to tell him that all L-series engines have two different exhaust ports, and that the idea is to equalize air flow in both port configurations throughout the valve lift-cycle. If he knows this then he will very likely know that the exhaust ports in L-series engines need more help than the intake ports, and also that total exhaust air flow should fall within the range of 75 to 80% of total intake air flow.

There are two separate and distinct approaches to the proper reworking of L-series Datsun cylinder heads and the correct route depends upon the application. For street or dual-purpose engines, shoot for as much air flow as possible at relatively low valve lifts and let air flow at maximum valve lift fall where it falls. The air flow curves should be good and fat at low valve lifts, on both intake and exhaust ports, without dips or "holes" in the curves, and if air flow doesn't increase much beyond valve lifts of 0.450 to 0.475-inch, who cares? When this is done correctly, gas velocity will usually be quite high for both intake and exhaust and the engine will show it by being very throttle-responsive throughout the normal engine speed range, but will be at its best in the mid-range and upper mid-range. If air flow through the ports more-or-less "signs off" at say, 0.460-inch valve lift, and the actual valve lift is in the 0.470 to 0.480-inch range, so much the better. This means the valves will be at maximum air flow rate for a longer period of crankshaft rotation and this will keep engine performance alive and well in the higher engine speed ranges. In such cases, camshafts with longer effective durations will not be as strong at lower en-



Barrel is lifted off and new rings fitted to bore. Hard to see, but a ring has been placed in the bore and the end gap of the ring is being measured with a feeler gage.

gine speeds as those with shorter effective durations in conjunction with fairly healthy valve lift numbers. But don't get carried away; those 0.600-plus inch lift numbers are *not* for street or dual-purpose engines.

Strictly race engines are of another planet. However, air flow at lower valve lifts cannot be abandoned in a search for the highest possible air flow at some ridiculously high valve lift figure. L-series Datsun cylinder heads can be modified to produce very good air flow figures at valve lifts in the 0.650-inch range, but this happens at the expense of air flow at lower lifts and has a detrimental effect on performance in the mid-range and even upper mid-range engine speeds. This occurs because the valves may reach the point of maximum air flow for only the shortest period of time, if at all, so the ports and air flow numbers, as magnificent as they may be, cannot be utilized effectively and the whole episode could easily dissolve into an exercise in futility.

By far the better plan, and one that really works, is to make every attempt to retain as much air flow at lower valve lifts as possible without giving anything away at higher lifts; not necessarily at the most extreme lifts, but at some reasonable and acceptable number say, in the range of 0.575 to 0.600-inch. Then the cam lobe profile can be made with enough additional lift so the valves are at or above the point of maximum port flow for a considerably longer period of time and/or crankshaft rotation. In this way, the engine does not give nearly as much away in the mid-range speeds, yet maximum power will very likely be at least as good, but more likely better than if extremes are attempted. I have seen some L-series Datsun ports that flow some extremely impressive numbers up to and including 0.750-inch valve lift but attempts to make use of these ports have been the most total, dismal and dreary failures imaginable, and for two very good but separate significant reasons. First, air flow at valve lifts below about 0.480 to 0.500-inch has never been enough to blow the dust off your desk-top. Second, the L-series Datsun rocker arm pads are simply too short to accommodate the type of cam lobe profiles necessary to generate such enormous valve lifts without running off both ends of the rocker pad, but there are secondary, nevertheless important, mechanical considerations as well. And the Datsuns are of relatively modest piston displacement, and they don't really *need,* nor can they use, all the valve lift in the world. Besides, you'd have to drain the oil to get the valves open.

Valve Springs—Stock Datsun valve springs are quite light and generally are not suitable for valve lifts in excess of 0.440 to 0.460-inch. Besides they stack solid at a lift of about 0.500-inch. They're fine for stock camshafts, but they are the engine speed-limiting factor with camshafts having higher valve velocities. The type and number of valve springs, and consequently the valve spring loading, depends upon the type of camshaft and the application. For street or dual-purpose applications, we usually advise a single damper-type outer spring with a load of 70 pounds with the valves seated and 210 pounds at 0.500-inch valve lift. This spring will accept a valve lift of 0.600-inch without overstressing the spring wire, so it has a lot of latitude without causing an overload condition between the cam lobe-rocker pad interface. Any reputable manufacturer of Datsun camshafts and valve train accessories will (or should) have enough variety of valve springs, spring retainers, lash pads, etc., to satisfy just about any requirement within the realm of reason.

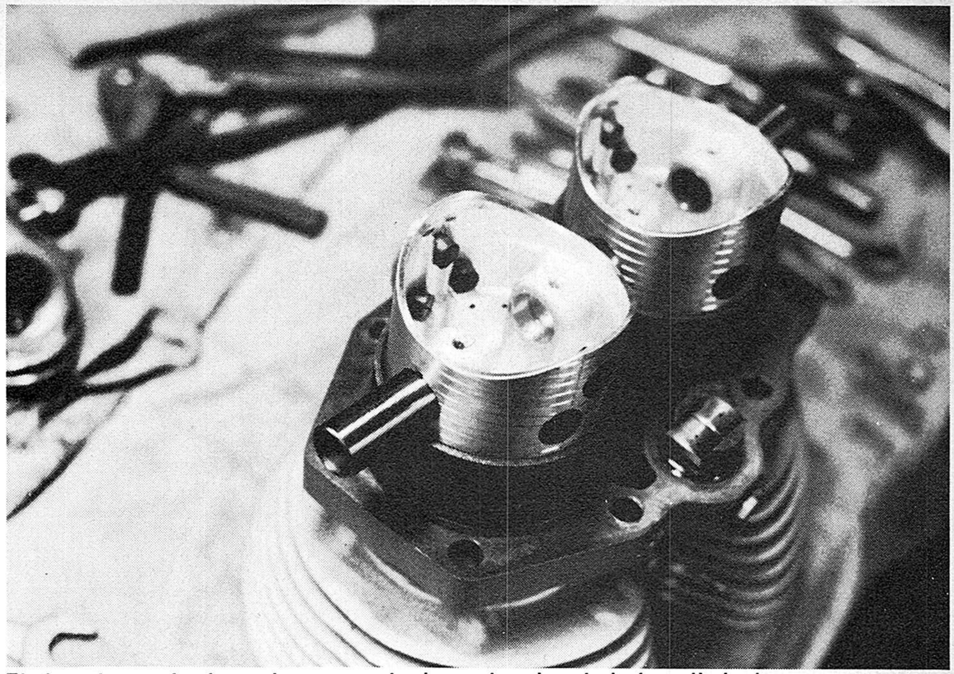
This doesn't mean that you should blindly accept his word for such things. Check out the spring load and assembled spring length dimensions to be *absolutely certain* that there is *no* possibility that the spring, or springs, will be stacked solid at or near full valve lift. There is nothing that is so quickly and completely destructive to the camshaft and valve train equipment as one or more stacked valve springs—and all it takes is an honest mistake in the valve spring load and/or assembled valve spring length dimensions on the timing card that accompanies the camshaft. Or, perhaps worse, the wrong valve springs with the correct specifications for the right springs.

In any case, *all* inner valve springs (if used) should be checked at full valve lift, *by themselves* first, because it is not possible to see through the outer spring coils and damper coils to determine visibly if the inner spring is stacking solid at or near full valve lift. And some inner springs will stack before the outers, and some damper coils will stack before anything else. It therefore becomes mandatory to check each individ-

ual valve spring and damper coil to ensure that stacking the valve spring assembly is not even a remote possibility. While you're running through this exercise, remember that the assembled spring length of the inner spring is always *shorter* than that of the outer spring by the thickness of the shoulder on the spring retainer, and in case stock Datsun springs are used, also by the inner spring shoulder in the cylinder head. A spring tester is the best way to handle this chore because spring length versus spring load can be measured simultaneously. If nothing else is handy, a drill press or even a bench vise can be used to measure spring lengths at the valve seated and full lift dimensions as a safeguard against stacking. Also, remember that only the springs are to be measured. Do *not* measure the spring retainers.

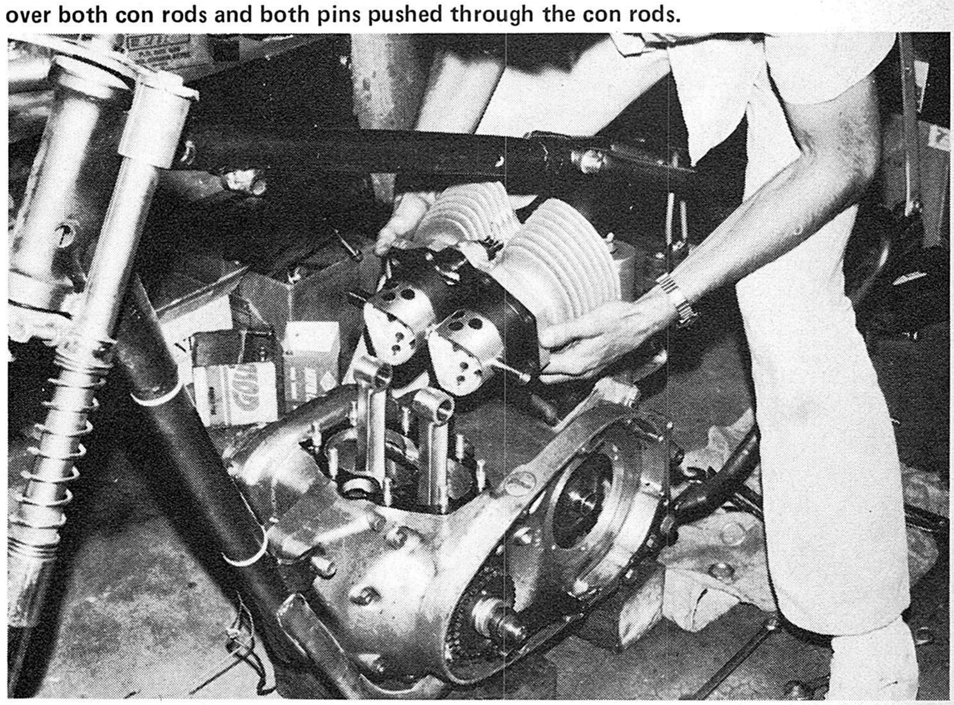
Valve springs, particularly race-quality springs, are among the most highly-stressed components of any engine assembly, but nothing lasts forever, so anything that can be done to ease the stress conditions of the springs will automatically make life easier on them and add to their longevity as well. Therefore, **RESIST** and **AVOID** the temptation of pulling the springs down to the last jillionth of an inch before they stack solid. All this accomplishes is an undesirably high spring load condition, but worse, causes premature spring fatigue, which ultimately results in spring breakage, and this is as bad as an armed hand grenade in the sump. Another bit of kindly consideration to the valve springs would be to remove the rocker arms if the engine is not to be used for awhile to relax the springs at least to their installed lengths, then pour clean engine oil over them and drop the cam cover on to keep out dirt and moisture. If the engine is to be stored for any length of time, it's best to remove the springs and store them in a can of clean and covered engine oil. A valve spring that picks up a spot of rust will break. There is no argument or speculation about that; the only question is—when? Probably when you need it the most in one piece.

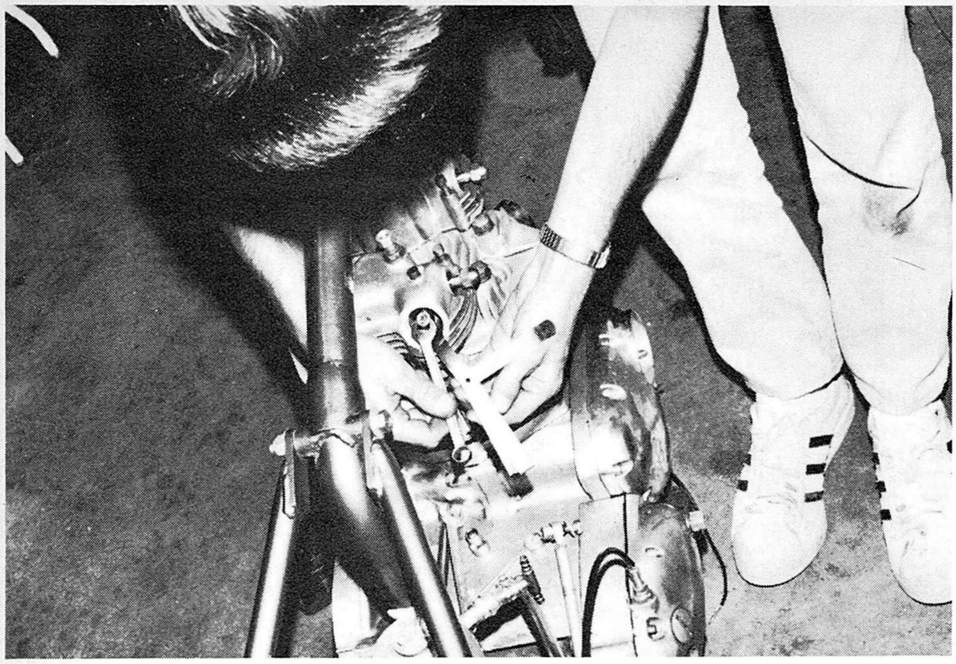
There are very few races in the world, and still fewer race courses, where total, maximum, last-gasp top-end horsepower is an absolute requirement for the fastest possible vehicle speed or lap time Some of these may include the Supertracks like Daytona (excluding the road race section), Talledega, Bonneville (the Great White



Fitting piston pins into pistons required reaming the pin holes a little, but now everything is ready to go back together. Pistons with rings installed are started into cylinders, pins are part way into pistons, waiting for con rods. Pistons are special, with teflon inserts on the thrust faces. Side-by-side tappets for push rods are visible at lower right.

All you have to do here is hold everything steady enough so you can get both pistons over both con rods and both pins pushed through the con rods.





Last step is to drop the push rods in and then set the rocker assembly in place, capturing the tops of the push rods so they are fitted to the ends of the rockers. Then valve clearance, or lash, is checked with feeler gages and adjusted to be right.

Dyno), flying kilometer time trials for boats and maybe, if the gearing is just right, Ontario, Indianapolis and LeMans. The vast majority of race courses, ashore or afloat, have one point in common: All other things being equal, the races become a series of short, medium or long drag races as far as engine performance level is concerned. This means that both the engine and the vehicle must have the ability to *accelerate,* a word that strongly and correctly implies that the engine must work at its very best through an engine speed *range.* There are no high-performance engines—none—that are run at constant, unvarying engine speed. If this were the case, an engine could be tuned to produce ultimate power output at a fixed engine speed to the utter exclusion of every other factor, and it would be very much easier to do so. Instead, all engines *must* operate through an engine speed range. Sometimes the range must be very broad, a condition that demands flexibility, even if it means sacrificing a few horsepower on the top end to gain the required degree of flexibility elsewhere within the working range. And flexibility spells *combination* much more loudly and clearly than it spells maximum horsepower effort.

About the least likely place on earth to qualify as a drag race is Bonneville, but it's true; it is indeed a drag race. The vehicle must start from zero miles per hour and reach its maximum speed within a fixed distance. If the engine doesn't have the ability to accelerate (that word again) because it lacks some essential factor for the right combination (that word, too), it's a waste of time because it isn't even an acceptable place for a vacation. The first-time Bonneville competitor invariably arrives with his equipment overgeared, overcammed, under-fueled, wrongly-tired, overcarbureted, under-jetted, wrong attitude of vehicle at speed, a totally inadequate air induction system and un-knowledged of the peculiarities and perversities of the place. Besides, he will have forgotten his metric toolbox. A week later, he leaves the wretched place with a truckload of fragments, a junk ex-race car and he has emergency hospital cases of sunburn, dehydration, malnutrition, hypertension, exhaustion, shock and a hangover. But it's a fun way to race, it affords a week-long opportunity to find the right combination, even if it was left at home, and it does give some insight into the mysteries of tuning for flat-out maximum power. But it is STILL a drag race.

In such a case, as rare as it may be, if better maximum power output is required to satisfy a given condition, you have to rob Peter to pay Paul.

Preceding text courtesy of:
Racer Brown
Racer Brown Cams
108 West Florence Avenue
Inglewood, California 90301

Guidelines To Modifying Your Motorcycle

Here are some general suggestions which may help you decide what to do, if anything, to make your bike more suitable for what you want to do with it.

RIDING IN CITY TRAFFIC

The very best modification is to sell the bike and get a car. My personal opinion is that the odds favor the car too much and I am not planning any bash-contests between my nose and somebody's fender.

HIGHWAY TOURING

The open road is lots of fun. If you have a suitable touring bike to begin with, the best thing to do is probably make it stock and enjoy it. You will preserve reliability, gas mileage, and good low-end performance. If you get your kicks out of going flat-out on the straights and taking the bends at the limit of adhesion, you are not touring. You are doing some *illegal* road racing.

RACING ON ROAD AND TRACK

You have to do what the other competitors do. Generally, these are highly-modified engines with lots of high-RPM power and not much at the bottom.

MOTOCROSS

There are probably 100 times as many riders racing MX today as any other form of motorcycle racing. Some of the manufacturers of motocross bikes haven't been able to make up their mind about what kind of performance is required and they switch back and forth from peaky, high-power-at-high-RPM type engines to more mildly tuned engines with less peak power but more low-RPM power. I think the reason for this dither is that it depends a lot on the rider.

MX courses have lots of places where you have to slow down to get around a turn. Then you accelerate along the straight to the next turn. The best riders don't slow down as much in the turns and are able to keep the revs up. These riders can use a peaky engine and it gives them an advantage in bombing down the straights.

An average rider does get slowed down too much in the turns and needs an engine with good low-speed grunt. I have seen average riders do worse on highly-modified machines than on stockers simply because they do not yet have the talent to keep the revs up.

So, what you do to your bike, or the kind of bike you buy for MX racing is determined more by your own riding ability than anything else.

OFF-ROAD RECREATIONAL RIDING

This means trail riding, cowpath, jeep road, fire road, sand wash, woods, or boonie riding, as you choose. This is really two kinds of riding.

One is play-racing in the dirt. These guys just like to go fast. They enjoy planing along the top of the sand in a long wash, screaming along dirt roads, doing power slides, and playing at MX or desert racing. Modified, peaky engines are common among these riders. Much of this type of riding is done in straight lines.

The other group of off-road riders are *really* trail riders who can cope with a sharp turn, a steep hill, or worse—a sharp turn halfway up a steep hill. Hotted-up engines are entirely unsuitable for difficult trail riding. Make it stock and leave it that way.

Many of the bikes sold as enduro or trail bikes are already too peaky for any kind of real trail riding. Whenever the trail requires these "enduro" machines to slow down and then pull strongly, they just won't do it. They bog down and die or load up and the rider doesn't have any fun. Sometimes a reed valve will help. If you are sensing a bit of prejudice in this paragraph, you can confirm it by looking in my book *How To Ride Observed Trials–Just for Fun,* where I have allowed my prejudices to become blatant.

OBSERVED TRIALS

In the above-referenced book, I have said that the way to make a good trials engine is to get some hop-up instructions for a racer and then do it all backwards. What you want is bunches of low-end torque.

ENDUROS, ISDT EVENTS, AND EXPEDITIONS

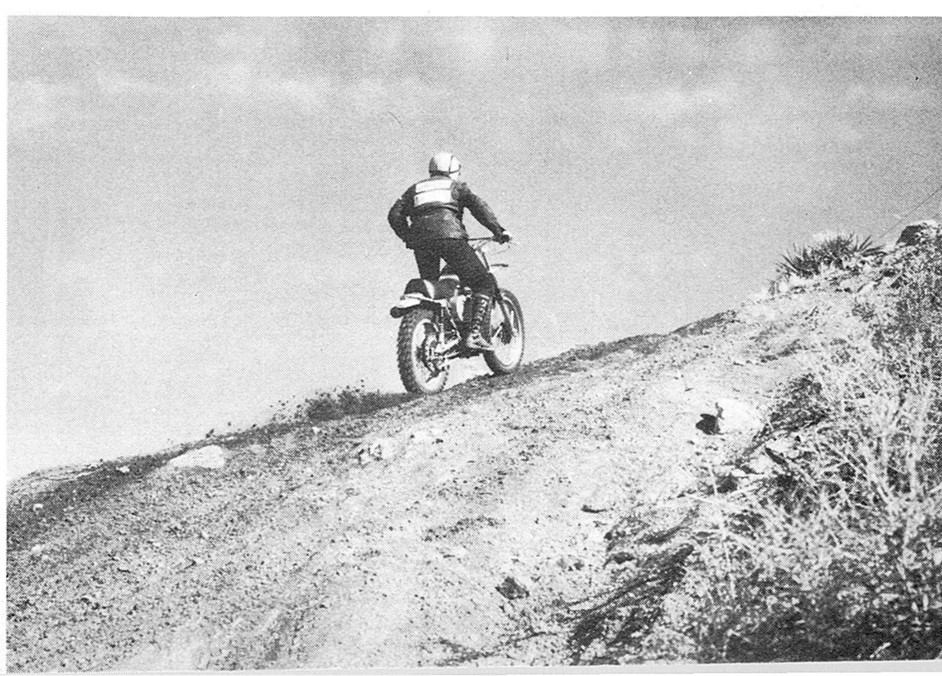
This kind of riding places maximum emphasis on ruggedness and durability. Peaky engines are out of place here, *however* some ISDT machines have been forced into peakiness to remain competitive in the speed contests which are part of the ISDT. Best guide is to make it stock and do things to add strength and reliability.

Two-Stroke Modifications

I was out riding with Wayne Ebaugh, he on his 450 Husqvarna and I on my 350 Bultaco Alpina. He said, "Here, take a ride on my bike."

I did, and it tried to bite me, so I gave it back to him and asked, "What did you do?"

He wrote it all down for us, in the following article.



This is Wayne Ebaugh, romping up a local hill which gets steep enough and loose enough to turn back about nine out of ten riders who attempt it. He is riding his 450 Husky after improving it as described in his article on the following pages. I have to say that my stock Alpina also romped up this little hill.

Improving The 450 Husky

By Wayne Ebaugh

The stock 450 Husqvarna is an excellent machine. After I had ridden mine a while I decided to make some changes which I thought would make it even better for the kind of riding I like to do on this type of bike.

These modifications make the motorcycle super-quick, with unbelievable throttle response. It is fast, but it will also start easily; it has lots of low end; and it still has Husky reliability.

To do this work, on a Husky or nearly any similar two-stroke, you need a set of metric wrenches, a set of small files, an electric drill and bits, a high-speed electric grinder with milling bits, machinist's rule, feeler gages, scribe, machinist's bluing, some #400 and #600 grit paper—Wet or Dry type—and an ample supply of both your favorite beverage and patience. If you take the time to do the job properly, I am sure you will agree that it was worth it.

The modifications are described in three steps:

1. Basic engine changes
2. Air-flow improvements
3. Fuel-flow-rate improvements.

STEP ONE: BASIC ENGINE CHANGES

Wash your bike thoroughly, being very careful to remove grit, sand and such, from the vicinity of all engine openings, flanges, and mating surfaces. A clean engine in a clean bike is much easier to work on and you will do a better job with less chance of getting crud into the engine.

Remove carburetor and exhaust systems, seat and tank. Loosen the cylinder head bolts gradually, each a half-turn at a time until they are all loose, then take the head off. Next, remove the piston pin retaining clips, piston pin, and piston. If necessary, heat the piston so the pin will slide out without undue force. Never hammer one out.

Install the piston, with rings, into the bore and check for wear according to your owner's manual. If parts need replacing, now is the time to do it.

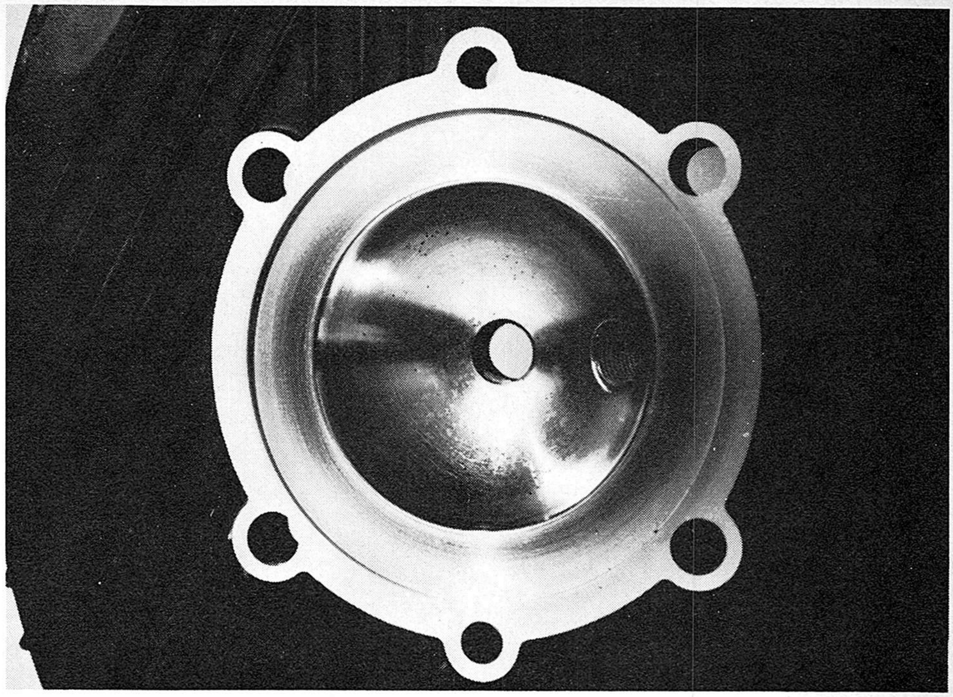
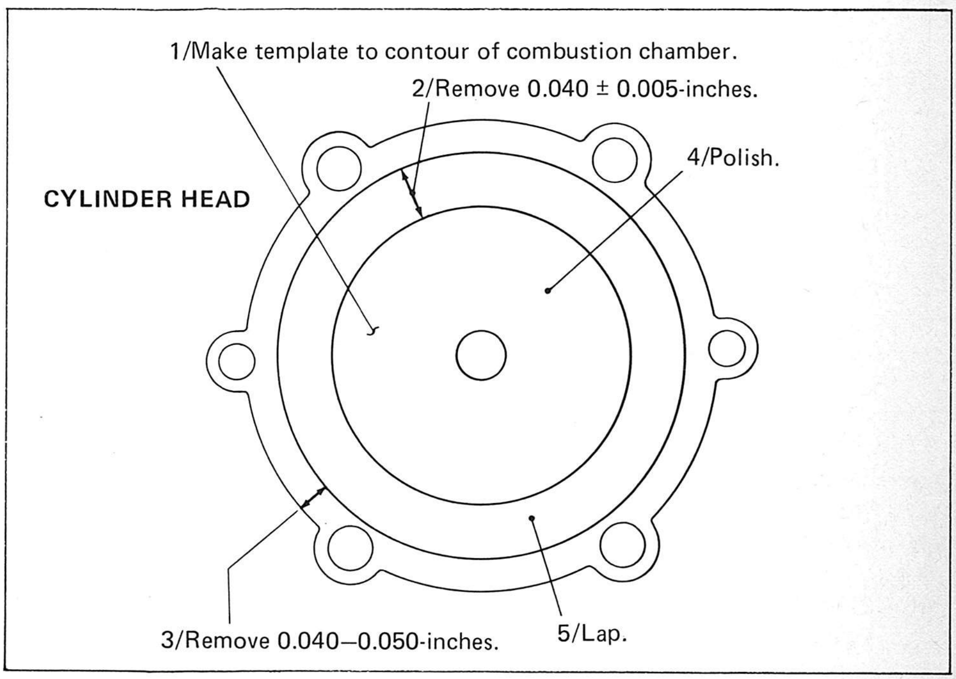


Figure 22—Photo shows head work done on a lathe by Kent Bowen of Albuquerque. After taking cuts off both flat surfaces, as shown in the drawing below, the combustion chamber shape was restored following a template made in advance from the original combustion chamber. The head has been lapped and polished by hand and is now ready for reinstallation.



The cylinder and head will require professional machine work which you may be able to have done at a local dealer's shop or at any good machine shop, preferably one equipped with a machinist having some motorcycle experience.

Before taking the head in for machine work, make a template showing the cross-section of the combustion chamber. Use 1/32 aluminum sheet or similar. Make certain that the shape is exactly like the original.

Then have 40 thousandths (plus or minus five) removed from the head. Now, using the aluminum template as a guide, have the combustion chamber reshaped to restore piston-to-head clearance. It is important to keep tool marks to an absolute minimum on the inner surface of the combustion chamber.

To restore original clearance between head and cylinder, *outside* of the gas-seal faces, 40 to 50 thousandths must be removed from the base of the head in the bolt-circle area as shown in the accompanying photo and drawing of Figure 22.

The head is now complete except for polishing and lapping. Polish the combustion chamber using the 400 and 600 grit paper on the

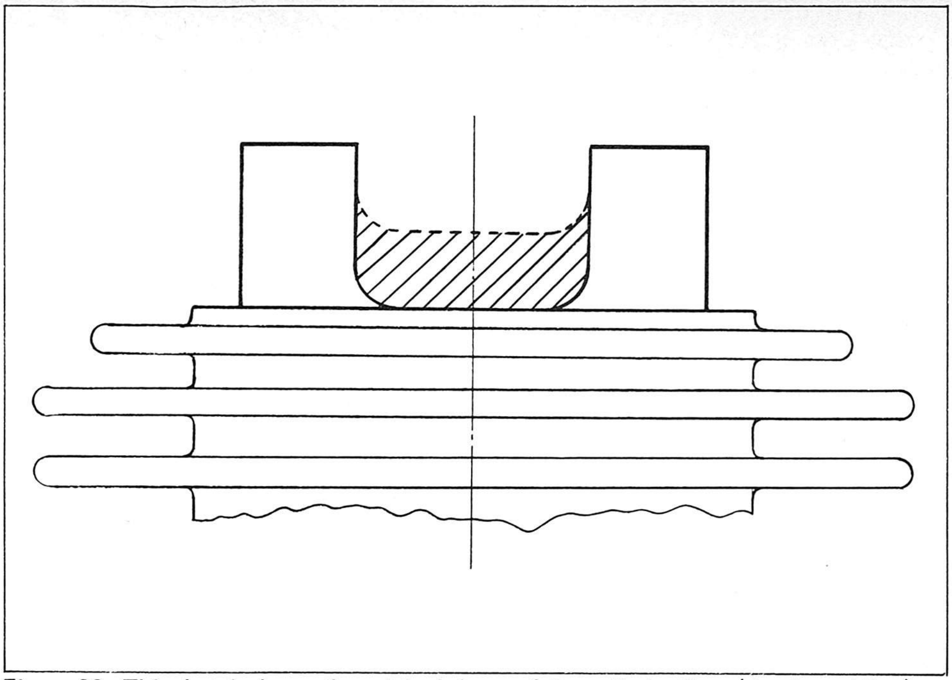
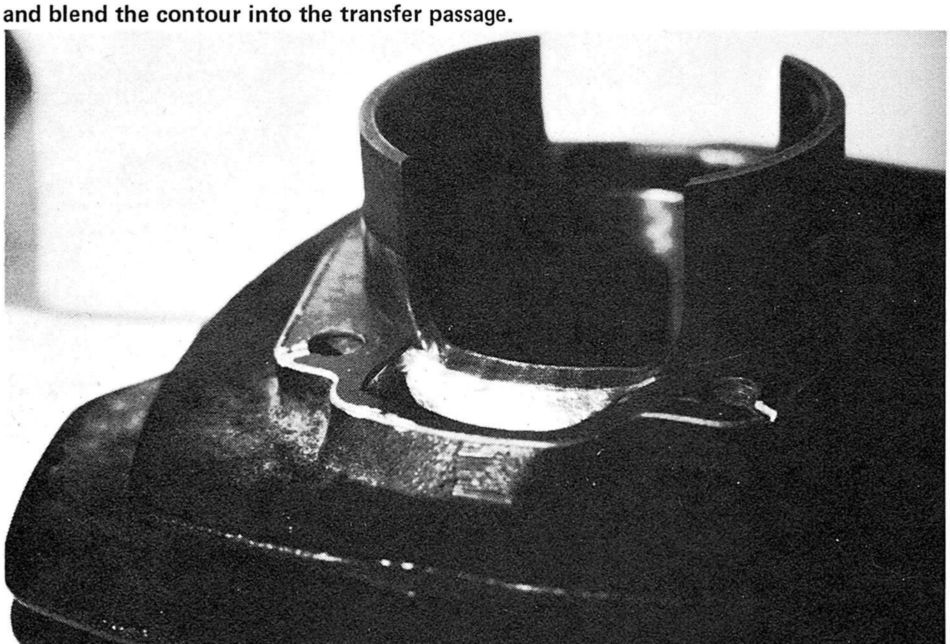


Figure 23—This sketch shows the original shape of the cylinder liner (the dotted line) adjacent to the transfer port passage. The shaded area represents material removed.

Figure 24—After machining, a hand grinder was used to taper the cut edge of the liner and blend the contour into the transfer passage.



Contributor Ebaugh writes of milling 0.040-inch off the head to increase compression— This is partly to compensate for the reduced air density at the 5,000-foot elevation where he and I live. I know this works OK at this altitude because I have ridden his Husky and I do the same thing myself. However at lower elevations, with this or any other engine, it is best to check with somebody who has done it before lopping off big hunks of metal from your engine.

Or maybe sneak up on it!

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end of your finger until it looks like a mirror.

Since this engine does not use a head gasket it depends on absolutely flat mating surfaces between head and barrel to maintain a seal. With increased compression it is worth taking the extra precaution of lapping this surface before reassembly. Using a bit of fine-grit lapping compound which the machinist will probably give you, lap the cylinder to the head. Simply put a little of the paste on the surfaces and rotate the head using an oscillating motion. Clean the surfaces occasionally with a damp rag and continue the lapping until both surfaces have the same texture and appear flat. Wash the head thoroughly with hot water and detergent, oil it, and set it aside.

Now, let's get to work on the cylinder. Figure 23 shows the original contour of the cylinder liner in the transfer-port area. The shaded portion which I decided to remove seems to obstruct flow of mixture from the crankcase, requiring it to make a U turn to get into the transfer passage. I couldn't see any good reason for this metal to be there, although Husqvarna must have a reason. I had the machinist remove the shaded area and the result is shown in Figure 24.

That was the easy part—all it took was money. The next part takes time and patience. Referring again to Figure 24, the U-shaped cut in the cylinder liner had a flat "bottom" which formed the inside wall of the transfer passage. I tapered this on the transfer passage side with a high-speed grinder. The taper makes an easier and more streamlined path for the fuel-air mixture to get into the transfer.

The remainder of the transfer-passage opening mates with a similar opening in the top surface of the engine case. Match up these openings by grinding away one or the other using the opening in the base gasket as a guide. Using files, abrasive bits in the high-speed grinder, and emery paper, smooth and polish the transfer ports and all areas you have modified. This is time-consuming but very important. Clean the cylinder thoroughly, coat with oil, and put it aside until later.

STEP TWO: AIR-FLOW IMPROVEMENTS

The stock 450 has numerous restrictions to air flow which should be removed where possible. The

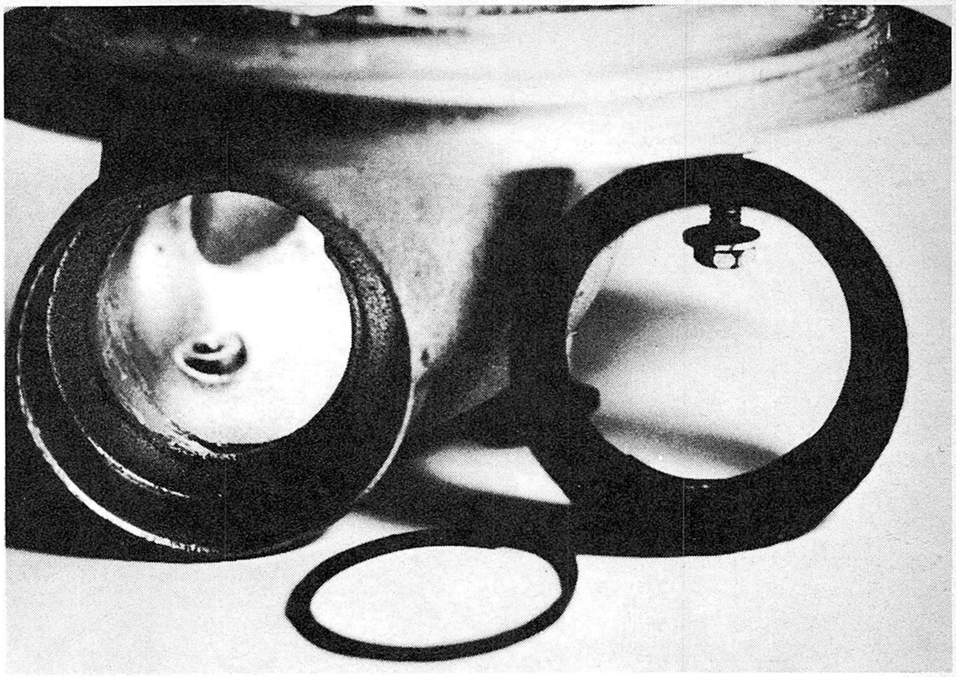
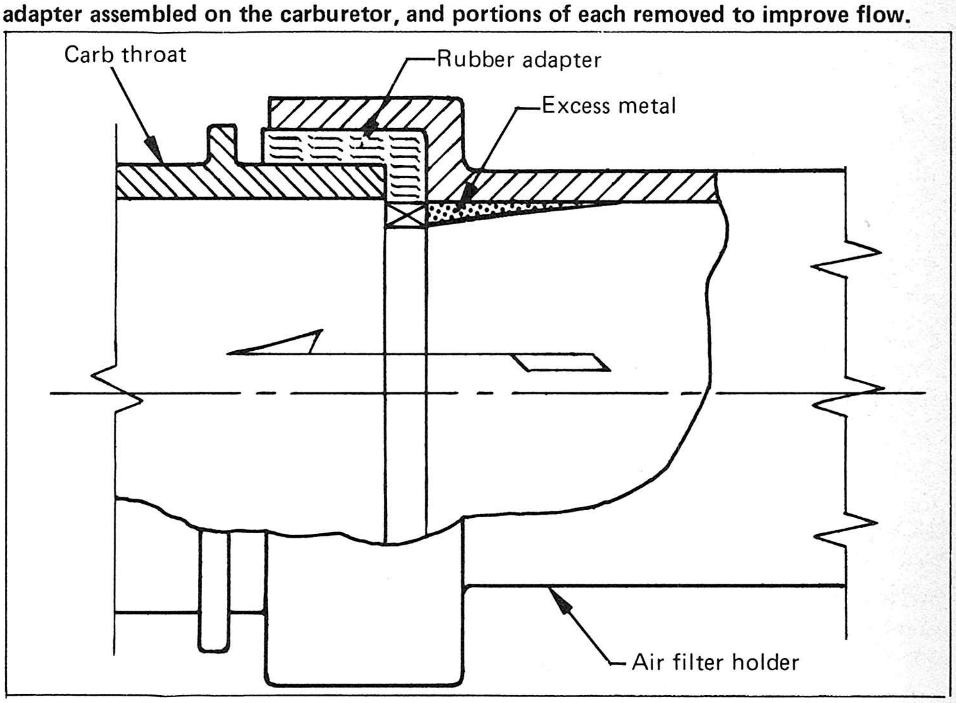


Figure 25—This photo shows the air-filter holder, the rubber adapter, and the ring of rubber which extended into the air passage and was removed with a sharp knife. After the rubber was removed to the diameter of the carb inlet, then there was excess metal in the air-filter holder. Photo shows this metal partially removed with a hand grinder, at left; original shape at right.

Figure 26—This drawing shows a cutaway section of the air-filter holder and rubber adapter assembled on the carburetor, and portions of each removed to improve flow.



carburetor is a 36mm Bing with a rubber adapter between it and the air-filter holder. The ID of the adapter is smaller than the air passage into the carb. By installing the rubber part onto the carb, you can reach in with a sharp knife and trim out the ring of excess rubber which will then provide both a larger and a smoother air passage, as shown in Figure 25.

Now, put the rubber adapter onto the air-filter holder and look through the combination. The metal part of the holder has a smaller ID than the rubber adapter which you have just enlarged. Reach in with a scribe and mark the air bell, then get the grinding tool on the job. After removing all excess metal, smooth and polish. That gets more air into the carb. Both of the changes are illustrated in Figure 26.

How about the passage from carb to crankcase? You guessed it! More restrictions. Take the slide out of the carb, put the carb in place on the inlet pipe and look in the direction of air flow. Scribe and rework with the grinder, then smooth and polish the reworked areas. This makes a nice smooth air passage, without any sharp discontinuities, between the carburetor and the intake manifold.

Now retrieve the cylinder barrel which you had parked temporarily, and match up the manifold, inlet ports, and mating gaskets with the grinding tool. Smooth and polish the intake port passages as shown in Figure 27, without enlarging them and being very careful to avoid creating any wavy or undulating surfaces. A flat surface which is moderately rough is better than a wavy surface which is mirror-smooth.

Now go around to the other side and do the same thing with the exhaust port and exhaust adapter, matching the openings and blending the surfaces into a smooth contour. The work I did is shown in Figure 28. Wavy surfaces are, again, undesirable. A mirror finish will help reduce carbon buildup here.

STEP THREE: FUEL-FLOW IMPROVEMENTS

For small-displacement scooters, the fuel flow-rate from standard hardware is sufficient. When you turn up the wick on a strong-running big bore, it needs lots of fuel and sometimes the standard arrangement is inadequate. This means larger diameters are re-

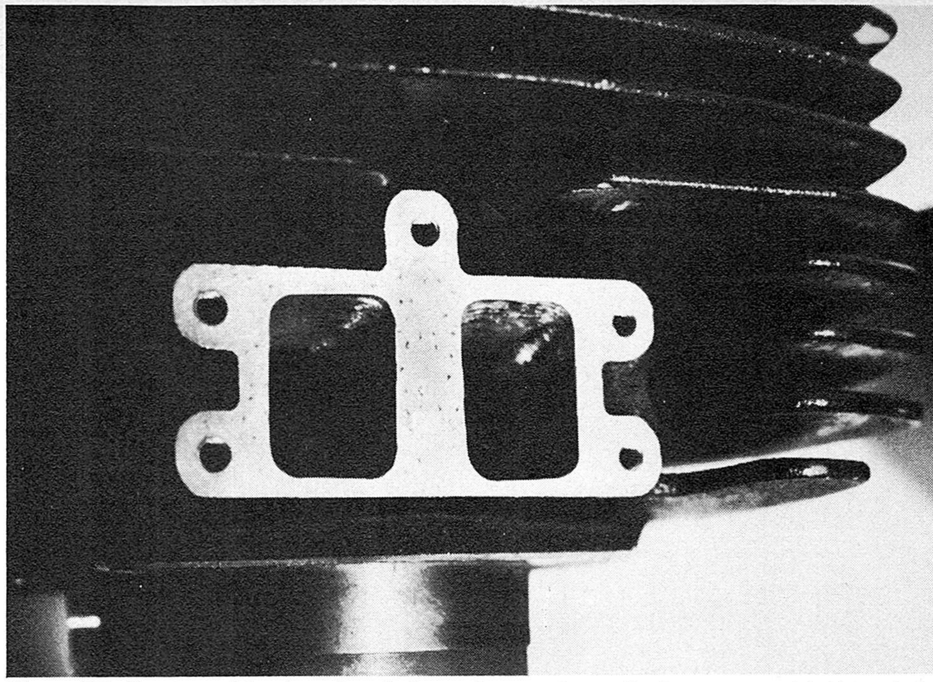
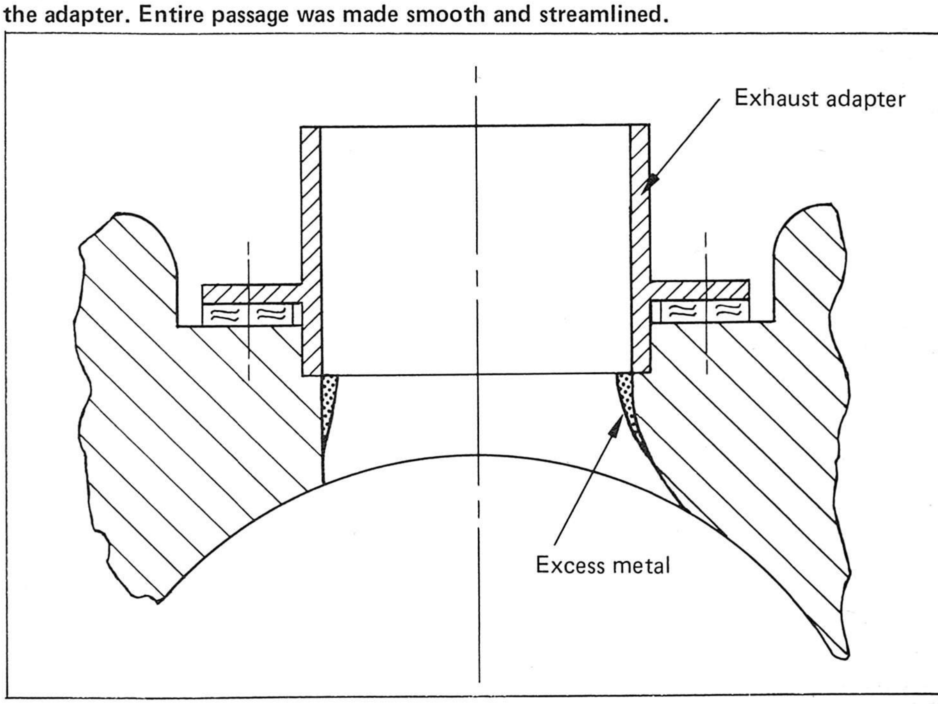


Figure 27—Port-matching has already been done and a preliminary pass with the grinder in the air passages shown. As stock, the passages in this barrel were rough, with lumps and bumps. These have been removed and the passages are now ready for polishing.

Figure 28—Cross-section of exhaust adapter fitted to barrel. The excess metal of the barrel casting was ground away to match the shape of the exhaust port to the shape of the adapter. Entire passage was made smooth and streamlined.



quired in fuel taps, fuel lines, fittings, and passages inside the carb. If you are running a fuel filter, be sure it has adequate flow rating for your engine.

Increasing the flow through a fuel tap can be done in different ways, depending on the tap design. In some cases, you can drill out the passages. On some taps with a reserve setting, you can drill through the rotating valve so that both the normal orifice and the reserve orifice flow fuel all the time. This is OK for race bikes but not so good for normal riding because you lose the reserve fuel capability.

The tap on my Husky is arranged so I could simply disassemble it and replace the lower portion with a 3/16" ID fitting from an auto parts store. The piece is shown in Figure 29. Replace the stock fuel line with 3/16" ID line of your choice. Remove the fuel-line fitting from the carb and drill it out to 3/16" ID also, as shown in Figure 30.

If the flow-rate into the float bowl is only slightly less than the peak engine demand at full throttle, the difference can be made up by the supply of fuel in the bowl for short periods. However if this happens when a rider is running full-throttle up a long sand wash, as I like to do, the bike can go lean and seize or burn a piston before the rider is aware of the problem. So, I continued the 3/16" ID fuel passage right through the interior of the carb, up the float needle valve, by drilling out the passage. Carefully!

Since the fuel which gets past the needle seat then has to flow along the sides of the float needle until it can escape finally into the larger volume of the bowl, I replaced the stock needle with one from a 27mm IRZ carb. The advantage of this needle is that it has grooves along the side so it obstructs fuel flow less. It also has a Viton (plastic) tip which I think seals better than metal on metal.

Finally, to be certain-sure, I enlarged the hole in the side of the fuel passage below the needle seat, as shown in Figure 31, so the fuel could dump out into the float chamber with minimum restriction. These measures may seem a bit extreme to some, but I haven't run lean yet.

That's all I did. I cleaned everything up and put it all back together. I did *not* change port timing or put on a larger carb

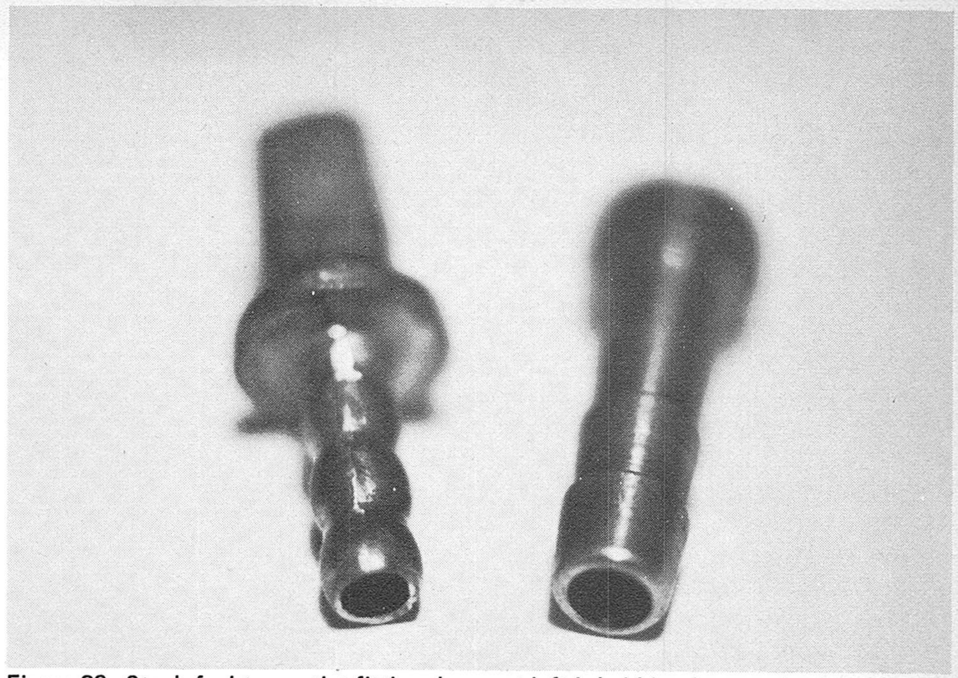
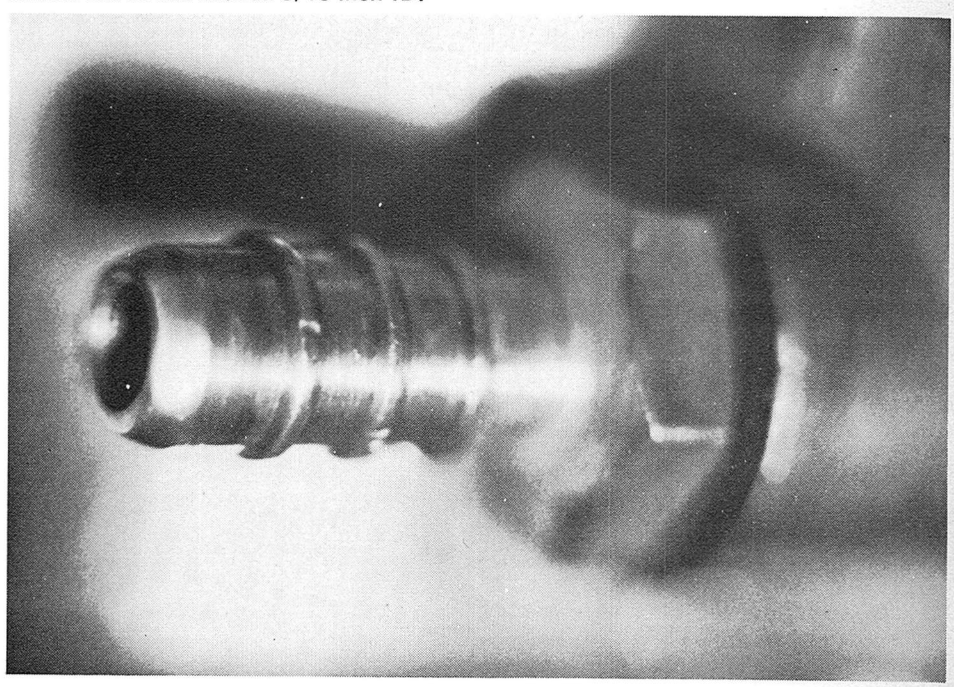


Figure 29—Stock fuel tap outlet fitting shown at left is held in place on the fuel tap body by a threaded ring. A replacement with larger ID was found at an auto parts store. The stock fuel tap has two mesh fuel filters, one above and one below. The lower mesh part of the stock outlet was lost in the conversion.

Figure 30—Fuel-line fitting on carb had enough wall thickness so it could simply be drilled out to the desired 3/16-inch ID.



because I didn't want to destroy the low-end performance of the engine. At 450cc displacement there is plenty of peak power anyway and these mods changed the plenty to an abundance.

I ran it a bit, taking plug readings and listening for any odd sounds among the typical clatter that a Husky engine makes. Then even though it was getting late in the day, I couldn't resist taking it to a nearby play-area where I have a favorite turn. Coming off the berm, I cranked it on in my usual way. The front end came up so quick the bike looped and put me on the ground.

Except for the compression change, the bike is basically stock—with careful attention to details. The difference in performance is startling, particularly the first time out, and well worth the time and effort to do it.

While these mods were described specifically for the 450 Husqvarna, they are applicable generally to any two-stroke and partially applicable to four-strokes. The important thing is to think any modification all the way through before you change anything to be sure there are no hidden surprises waiting for you. Whenever possible, get exact information and advice for your particular engine from someone who has made improvements successfully.

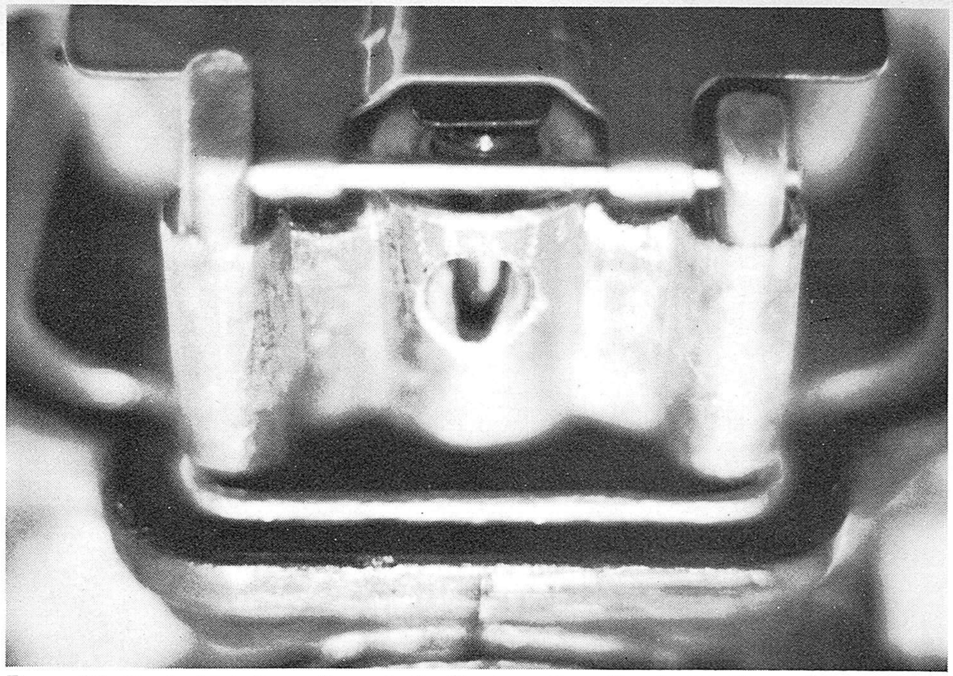


Figure 31—Fuel which flows through the float-needle orifice in this 36mm Bing carb enters the float bowl by two routes. One is the narrow passages along the sides of the needle. The other is three angled holes drilled into the carb casting leading from the valve seat directly to the float chamber. One of these three angled holes was greatly enlarged using a hand grinder and a miniature needle-point milling bit, to remove any possibility of fuel restriction in the float needle area which could result in fuel starvation during sustained high-speed running.

Please notice—Wayne Ebaugh *did not* attempt to enlarge the needle seat in his carburetor. He made the fuel passage larger up to the seat and made it easier to get fuel into the bowl once it had passed the needle valve seat. Machining a seat is a precision operation and you just don't do it with a handy quarter-inch drill motor.

Also, the smaller the seat the more effective is the closing pressure exerted on the needle by the float. If the needle has to seal off a larger circumference it may tend to leak more readily.

If you have done all the other things Wayne recommends and you are still starving for fuel then you can point to the float valve as the culprit.

Later in this book is a discussion of flow-rate measurement which can help you decide if you need to do anything at all.

There are rumbles emerging from some automotive hop-up experts—that deliberate mismatches in gas-flow passages are sometimes beneficial. This is contrary to classic theory but lots of classic theories have bitten the dust when they collide with demonstrable facts. If Husqvarna was using any such gas-flow trickery, Wayne may have obliterated it with his grinder. However the overall result of his work was a definite performance improvement.

Also, it should not be concluded that the grinding and matching on the Husky was indication that the engine was not made right. A small amount of matching and alignment is necessary on *any* production engine and everybody who tunes them grinds away these variations.

HOW TO FIGURE AND MEASURE FUEL-FLOW RATES

The drastic measures described by Wayne Ebaugh in the preceding section to get some fuel into his carburetor are likely to cause you to worry some about your machine and wonder if you should do the same thing. Running out of fuel while using peak power is more common than you would think, particularly with large engines.

Here are some ideas which will help you decide what to do:

Most engines are rated according to developed horsepower, torque, *and fuel consumption.* This was shown on the engine performance curves for Honda and Kawasaki, back on pages 10 and 11. As you know, two-strokes are likely to blow some unburned mixture out the exhaust during the scavenging operation and consequently you can expect the fuel consumption to be higher than four-strokes.

The U.S. way of specifying fuel consumption is in pounds per horsepower-hour, and the number for some particular engine might be 0.5. This means that for each horsepower generated by that engine and maintained steadily for one hour, the fuel requirement will be one-half pound of gasoline. If the engine put out 40 HP for an hour, it would consume 20 pounds of fuel.

The rest of the world (almost) specifies *specific fuel consumption* in grams per horsepower-hour, and that is what is shown on the curves mentioned above. As I read them, the Honda needs 260 grams and the Kawasaki needs 310 grams. These numbers convert to about 0.57 pounds and 0.68 pounds, respectively.

No rider is likely to run his engine at peak power for a full hour, however the *flow rate* which can be derived from a specific fuel consumption spec will express the need of an engine anytime it is operating at full power, whether it is for a long or a short period of time.

To actually come to grips with the problem of flow rate, it is more convenient to think of the demand in terms of gallons per hour, which anybody can measure with a bucket or a baby bottle. Let's make another conversion.

Adding a *safety factor* to the flow rates we have seen for a two-stroke and a four-stroke, we might decide that our engines need an assured supply of at least one pound of gasoline per horsepower-hour. Gas weighs about six pounds per gallon, so in volume we need to supply 1/6 of a gallon of fuel for each hour for each horsepower. And, we need to provide for the peak-horsepower fuel demand of the engine.

I had a 125cc bike once which was rated at a mighty 12 horsepower. It needed a fuel flow rate of two gallons per hour (12 x 1/6) everytime it operated at full power. An engine which develops 48 horsepower will require eight gallons per hour. You can of course flow more and have a larger margin of safety.

Once you figure the flow rate you want to assure for your engine, then all you have to do is measure what it actually is. Open up the carb, let the float drop down so that the float needle valve is open, arrange some way to collect the gasoline which flows through the needle valve, and measure the amount you collect over a measured interval of time.

There is a good chance that you will stumble around being scientific about reading the clock and kick over the gas container. **Do not** do this in your garage next to your hot water heater. Do it outdoors. Please!

If the flow rate is adequate, put it back together. If not, do things like Wayne did to his bike, leaving any needle and seat mods until the absolute last.

I measured the flow rate of a 125cc, 18 HP race bike recently and it was three gallons per hour. Just right, including the margin for safety. The 250cc bike of that same brand uses identical fuel line parts! If I owned the 250cc version I would make it flow more fuel.

FOUR-STROKE MODIFICATIONS

If we say that a basic engine does not include the carburetor and exhaust system, then we can make a generalization:

Two-stroke engines can be extensively modified without buying many parts. Most of the changes are made to the existing pieces of the engine, by removing metal. The opposite is true for four-strokes. Most modifications are made by removing original parts and substituting custom-made items.

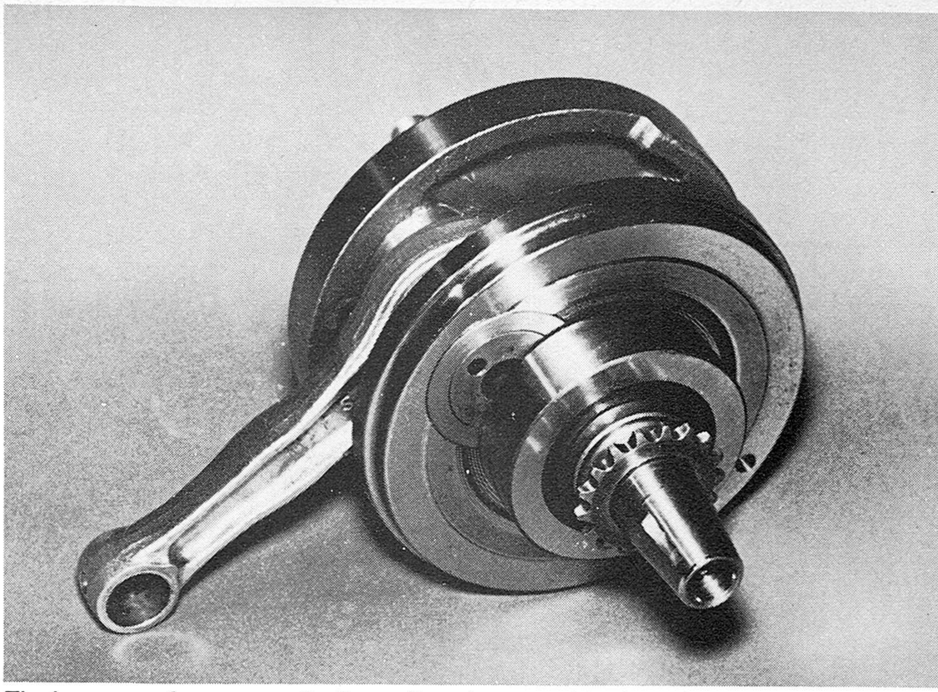
Accordingly, for a discussion of modifying a four-stroke I asked the Honda specialists, Powroll Performance Products, Inc., to provide the following description of their approach to performance and some pictures of the custom parts used.

If you own a Honda, and are interested in the Powroll route to power, you can get their complete catalog for $1.25 or a smaller catalog for your specific model for 50¢ by writing to:

Powroll Performance Products, Inc.
P. O. Box 1206
Bend, Oregon 97701

Modifying The Four-Stroke Honda

By Paul Olmstead and Jim Foushee



The long arm of power . . . the Powroll stroker assembly. Lengthening the stroke provides greater mechanical advantage and increased displacement to put more power on the ground.

Before we plunge headlong into how to hop up the four-stroke Honda, it is helpful to know basically what we have before we start.

The Honda four-stroke engine is an overhead-cam engine that develops its maximum horsepower at relatively high RPM when compared to the European marques that set the standard for so many years. The engine has generally established itself as "bullet-proof" with a tuning parameter that suggests a rock and pair of pliers can pretty well get you "close enough." In short, the engine seems to be able to run forever even though it may be way out of tune.

By the very fact that you bought this book, you have expressed an interest in gaining additional power from your bike. Each section has covered the specific areas of concern. But you still may want more. You may have been beaten by someone on a Honda who isn't as good a tuner as you and isn't a better rider . . . so how did he do it?

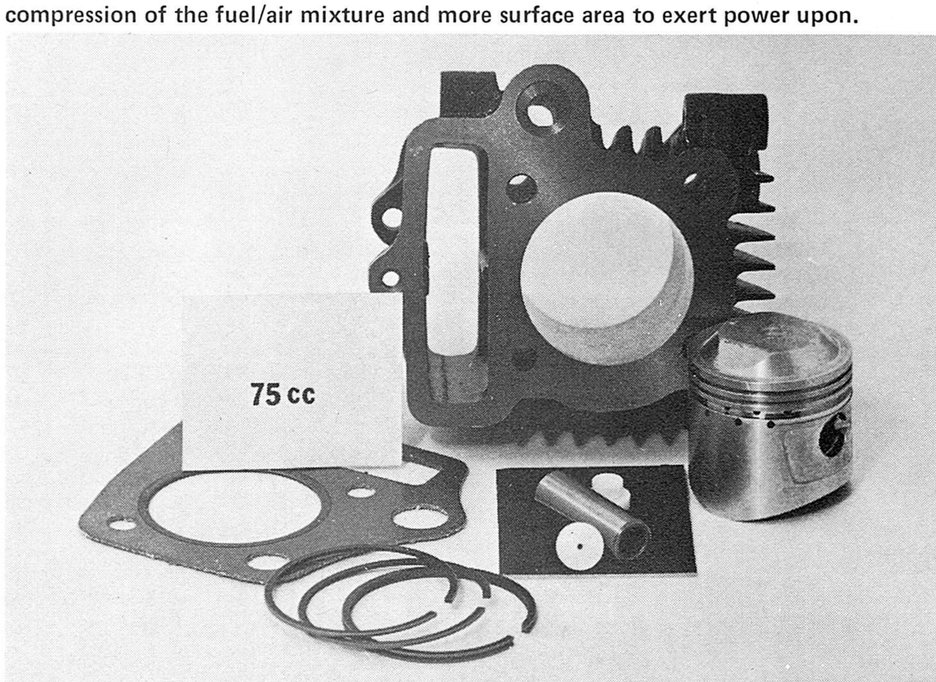
TWO PHILOSOPHIES

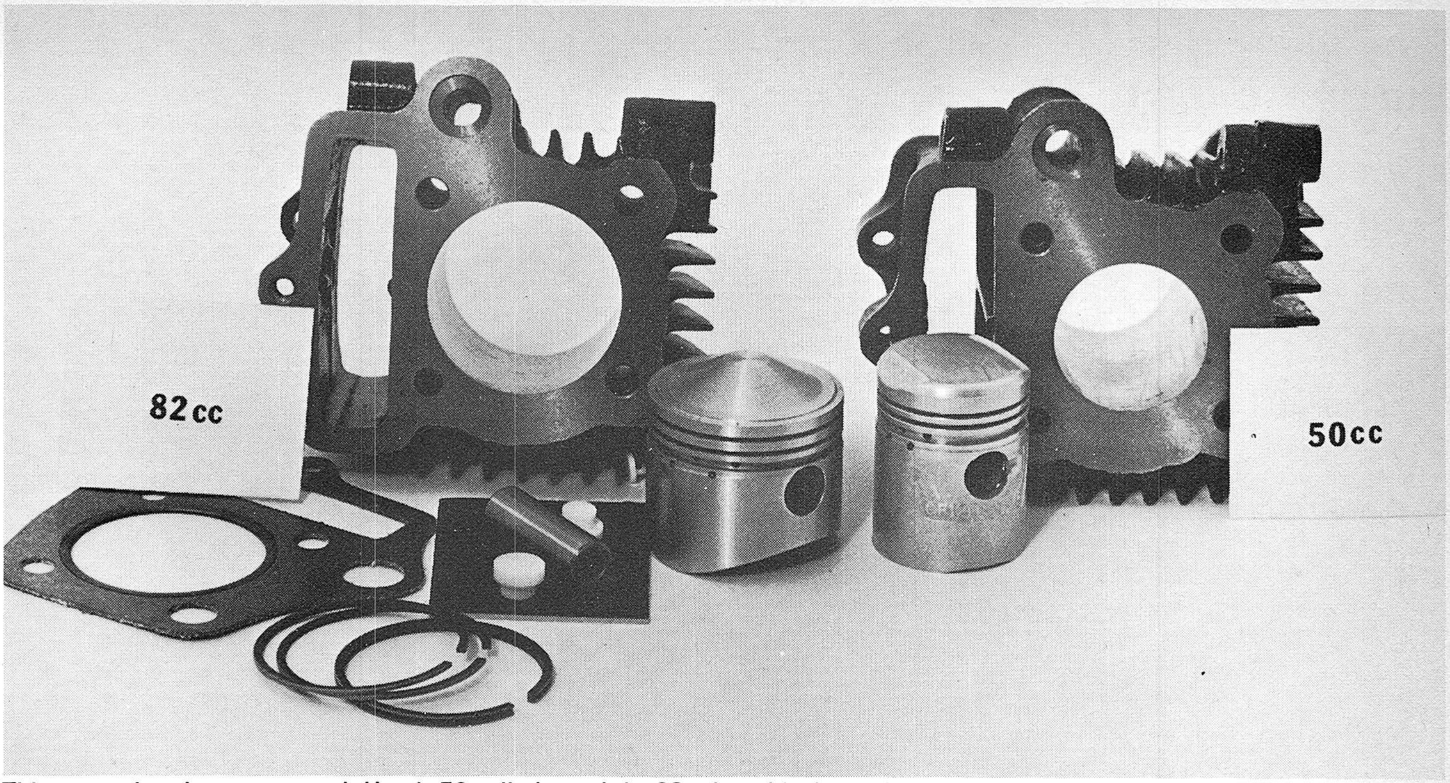
To begin with, there are two basic approaches to hopping up the Honda. Extend the RPM range and improve the efficiencies at these high-RPM levels. The use of smaller drive sprockets, high-RPM cams, bigger carbs, and generally improving the flow characteristics of the engine through extensive work is typical of this method. The performance is there, but the engine has to be kept revved up to use it.

Displacements usually remain nearly stock due to competitive restrictions and the alterations above are done to the extent they are allowed or budget permits.

Another approach is to increase power from low RPM up to the stock redline. This is the common objective of the dirt racer, trail rider, impromptu street dragster, or bike

High-compression over-bore pistons offer two advantages. More power due to higher compression of the fuel/air mixture and more surface area to exert power upon.





This comparison between a stock Honda 50 cylinder and the 82cc bore kit shows there is nothing like more cc's to add torque and power.

owner who for his riding style wants more power without requiring excessive RPM. This is the position assumed by Powroll Performance Products.

It has been our experience with the Honda that additional horsepower and torque can be added with confidence, if done properly.

THREE WAYS TO MORE POWER

Big-bore kits, high-compression over-bore pistons and stroker cranks are the basic elements used by Powroll. In addition, a cam and tuned exhaust may be necessary for development of maximum power from the basic elements.

With a larger piston, there is more surface area for the combustion of the fuel-air mixture to act upon, producing more torque.

High-compression over-bore pistons offer the benefits of a larger piston plus additional power due to several important facts. The fuel-air mixture is more highly compressed. When the denser mixture is ignited, the burning gases expand, applying more pressure during the power stroke. There is also an increase in temperature with high-compression pistons and they are only recommended for competition where speeds are sufficient to effect proper cooling.

The stroker crank offers additional torque by increasing displacement and providing more mechanical advantage. The distance to the center of rotation is increased, therefore increasing the leverage, much the same as a long-handled wrench can exert more force than one with a shorter handle.

These are the three basic options for increasing power in the engine up to redline. The most effective way to increase torque in the singles is the Powroll stroker assembly. Stroker cranks for the twins and fours are not offered by Powroll as of 1973.

Your objective of more power is therefore influenced by what's available, your ability to do the work, or the budget to pay to have it done.

Powroll offers modifications that provide power and reliable service if installed and maintained properly. A very important factor influencing all engine life, especially high performance engines, is a proper state of tune as outlined in the owner's manual. This means throwing away the rock, chisel and pair of pliers and replacing them with feeler gages, an assortment of main jets, some fairly reliable means of timing the engine, and at least the basic tools that came with the bike plus the determination to maintain at least a good state of tune.

WHAT CAN HAPPEN

Why the seeming overemphasis on tune? When you opted for more power you gave up something . . . that super-wide tuning parameter. Increasing the compression makes detonation or pre-ignition more likely in a poorly tuned engine. Increasing displacement (it happens with a stroker as well as the big-bore kits) increases the heat because the volume of fuel-air mixture is greater. The engine normally can dissipate this additional heat with no adverse effects. When the condition is aggravated by lean jetting or improper ignition timing it causes excessive heat buildup and pre-ignition. This causes more heat and consequently more pre-ignition and the cycle spirals until . . . disaster!! Just a footnote, this happens in stock engines, too.

Another problem is detonation often caused by a hot spot, low-grade gas, improper mixture, or too much total ad-

vance. Powroll recommends using a timing light and setting the total advance to the mark closest to the F mark.

NOTE: Refer to previous sections on carburetion and ignition in case you skipped it or only hit it lightly. It is very important to understand these two factors and their relationship.

Hopefully, by now you have been convinced of the relative merits of keeping an engine in tune, especially a modified one.

HOW TO FIGURE DISPLACEMENT & CR

It is only fair to mention at this time that there are those who advertise big cc bore kits who would have to relinquish their claims when a little mathematics is applied. The following is the formula for figuring displacement:

(½ the bore in cm)^2 x 3.1416 x stroke in cm x number of cylinders = displacement in cc's.

For a SL 125 Honda:

bore = 5.6 cm

stroke = 4.95 cm

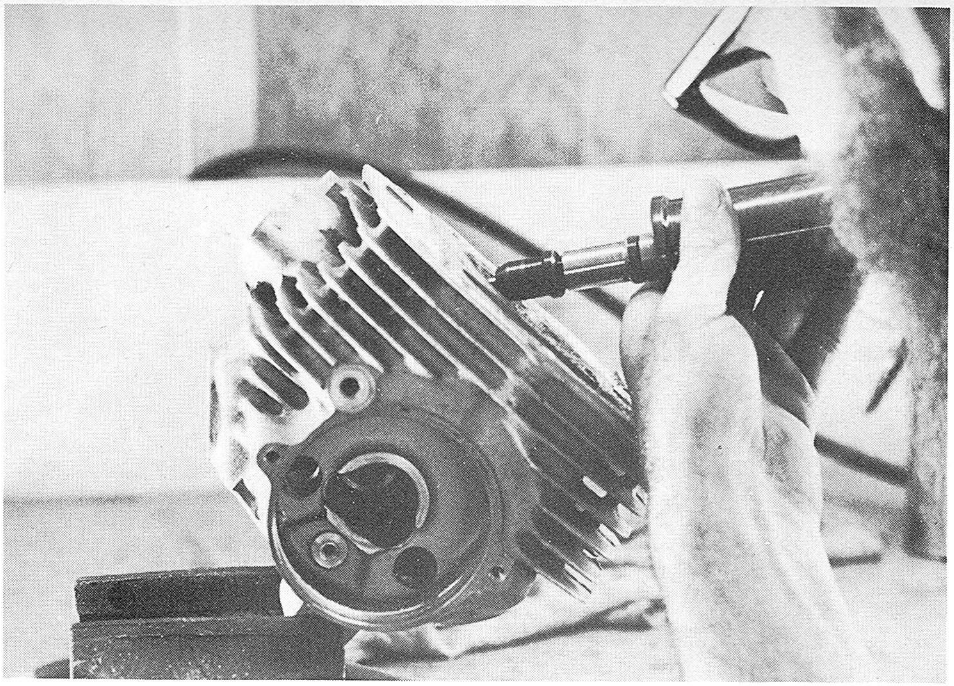
2.8 x 2.8 = 7.84 7.84 x 3.1416 = 24.63

24.63 x 4.95 = 121.9 cc's

NOTE: This formula uses centimeters. If you have bore and stroke in millimeters, divide the numbers by 10. Example: 54 mm = 5.4 cm.

As long as you have gone to the work of figuring the displacement you may want to compute the compression ratio. You will need a method of measuring cc's, a 20cc syringe works very well.

Remove the spark plug and tip the engine until the top of the hole is in a horizontal plane. Be sure the engine is at TDC on the compression stroke when both valves are closed. Fill the combustion chamber with 10 weight (or lighter) motor oil until it reaches the bottom of the spark-plug hole; noting the number of cc's it takes to fill the combustion chamber. Now all you need is the following formula to arrive at the compression ratio: divide the engine displacement by the combustion chamber volume and add 1.



Headwork improves breathing. This type of modification is definitely the racer's edge and may not be fully appreciated by the trail rider because its effects are usually only discernible under comparison with an equally matched rider in competition.

Whether it is competition or less demanding circumstances the Honda four-stroke can be made to perform with the proper modifications. The trick is deciding what you want . . . high-RPM horsepower? Or power up to the stock redline?

$$\frac{\text{Engine displacement}}{\text{Combustion volume}} + 1.00 = \text{CR}$$

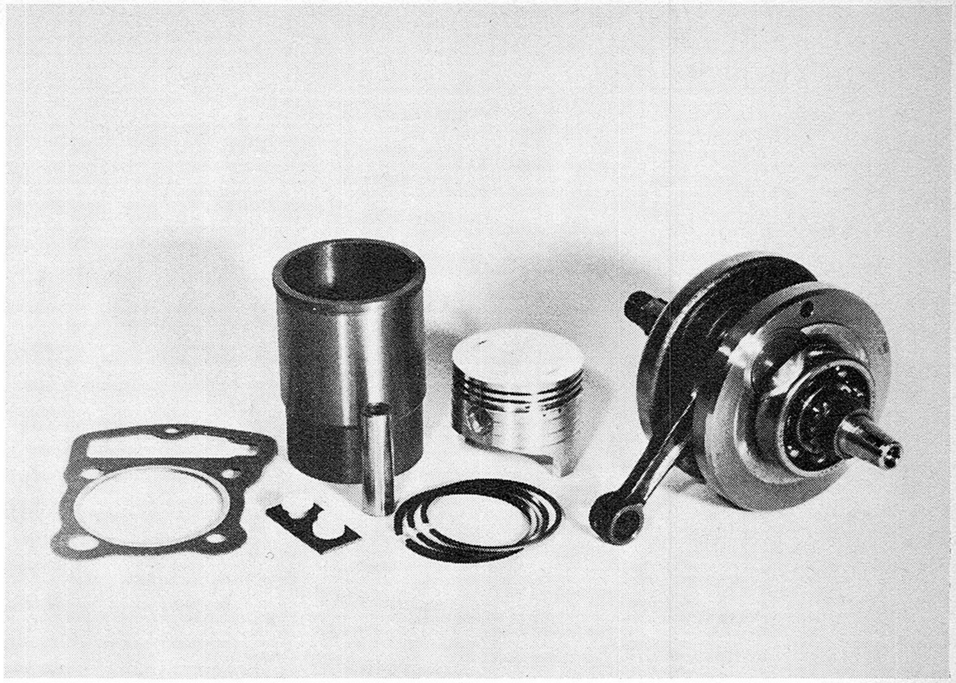
Or, for our 125:

$$\frac{121.9}{13.55} = 9 + 1 = 10{:}1 \text{ CR}$$

HOW BIG?

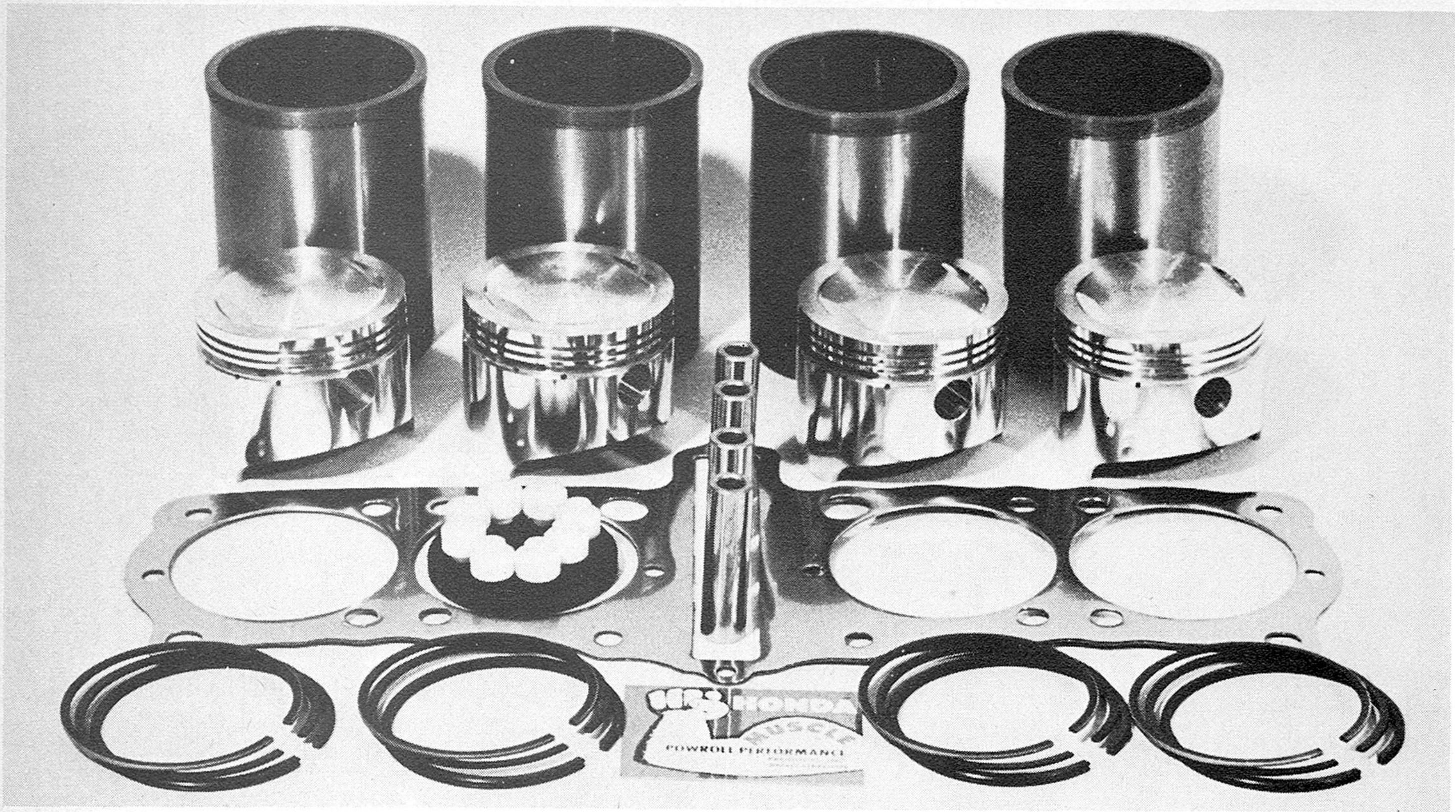
Powroll uses a rule of thumb based on years of experience with the Honda air-cooled engine. We call it the "50% rule": Generally, exceeding 50% of the engine's designed displacement saturates the engine's volumetric efficiency. Simply, the engine cannot move the F/A into the engine or remove the exhaust efficiently enough to develop full horsepower potential.

This problem is brought to the surface when very large diameter pistons are used, or in some cases, when bore and stroke are combined. For example, Powroll offers a 63mm bore kit for the 100. When it is combined with the stroker the resultant displacement is 185 cc's. The 50% rule says about 145 cc's. In practical application the engine has excellent torque characteristics, it pulls like a tractor in every gear until the engine's breathing ability is saturated. Unfortunately this breathing efficiency is significantly below the engine's horsepower capability. It can rev well above stock redline, but since the efficiency is saturated at a lower RPM, the full horsepower potential is not realized. Where torque in the low and mid-range are the objective and plain slugging-away power are needed, the 185 cc's makes its mark, but where total RPM capability is required, something well within the 50% rule is preferred. Now—like any rule—there are enough exceptions to make one wonder how the darned thing ever got started in the first place. Let's look at the SL 125 engine. It was first designed as a 100, the most significant change to the engine was the addition of a 56mm piston, so when applying the 50% rule, computations are based on 100 cc's not 125. As for the mini's, the head is essentially a 50 even on the 65 and CT 70. The SL 70 has been redesigned so it handles 100 cc's quite well, but comes to grips with the 50% rule at about 108 cc's. The exceptions are many, but generally consider the 50% rule when planning modifications.



Combining bore and stroke results in excellent torque but due to the increase in displacement there is a loss of total RPM capability. Exceeding 50% of an engine's designed displacement interferes with the engine's volumetric efficiency.

Photos courtesy Powroll Performance Products.



Some bore kits require over-size sleeves to retain Honda reliability. Pictured is a 1,080cc bore kit for the 750.

A natural question at this point is "What about big valves, or can a super big cam change the situation?" In Powroll's testing of the 100/125 engine for example, we have arrived at several basic conclusions. Bigger valves alone do not extend the 50% rule. A cam to provide enough overlap to alter breathing characteristics to exceed the 50% rule requires extensive modification and cost.

Honda has designed their engines for specific volumetric efficiencies, hence the 50% rule. There is a higher level of potential power available when the proper modifications are done.

After the installation of equipment to increase displacement, the addition of a cam and tuned exhaust system is often recommended to improve breathing and extend the effective RPM range. For example: Installing an 83mm bore kit in the XL 250 (312cc's) expands the power band to start pulling strong from an idle. To develop the maximum horsepower, however, it is necessary to increase the breathing efficiency, requiring the addition of a cam and tuned exhaust.

WHICH FOR YOU?

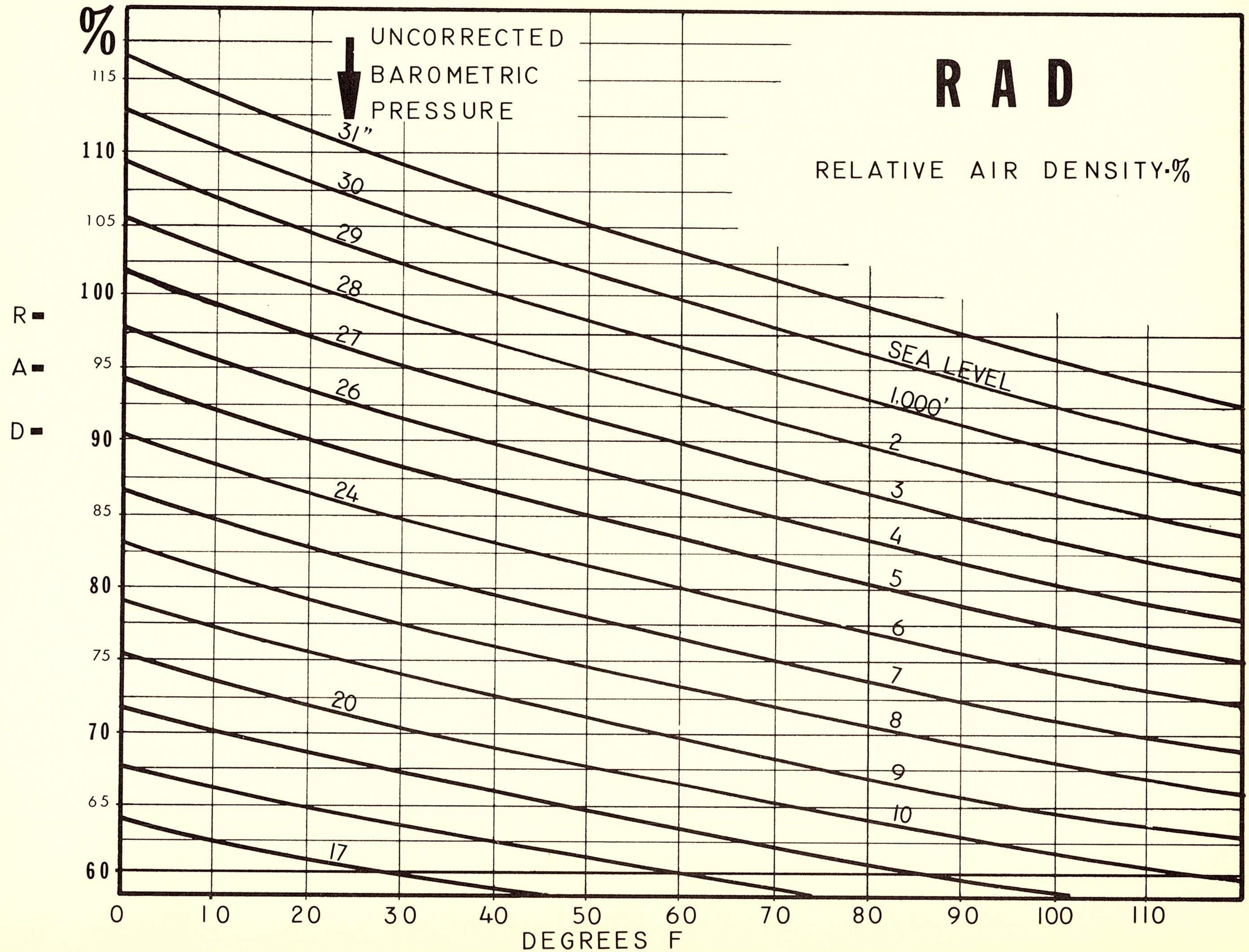
In improving the power output of the Honda four-stroke the approach is governed by the intended use. A high-RPM, big-horsepower modification may be just the ticket for a Daytona-type application. It has all the big numbers, but one very important one—the RPM—would disqualify it for the touring fan. A drag bike is not a trail bike and many a rider has been disappointed because his selection of modifications resulted in more horsepower but also required higher-RPM operation which—due to his riding application—proved unsuitable.

Increasing the displacement primarily affects the low and mid-range performance. As long as the 50% rule is observed, the top-end performance will also be improved but not to the degree of that in the low and mid-range.

Decide the results you want before you decide what modifications you want. What are your objectives, high RPM horsepower or a good wide range of torque and power?

temp		press		TUNING RECORD				date		place
RAD	MAIN JET	NEEDLE POSITION	IDLE JET	IGNITION TIMING	COM-PRESSION	PLUG	PLUG READING	PERFORMANCE FULL	PERFORMANCE HALF	NOTES

Index



RAD
RELATIVE AIR DENSITY·%
UNCORRECTED
BAROMETRIC
PRESSURE
31"
30
29
28
27
26
24
20
17
SEA LEVEL
1,000'
2
3
4
5
6
7
8
9
10
%
115
110
105
100
95
90
85
80
75
70
65
60
R
A
D
0
10
20
30
40
50
60
70
80
90
100
110
DEGREES F

"Ever wonder what compression ratio or ignition timing really was? This book by Carl Shipman will give you enough basic theory to understand what his suggested hop-up techniques are achieving and why. Even if you don't intend to modify your bike at all, the book is excellent for reference." —Cycle Buyers Guide, 1973

" . . . just about everything you need to know to get maximum performance from a stock engine. . . . 'Tuning for Performance' contains cogent explanations of the operation and adjustment of carburetion, ignition and gearing. It has a very useful chart indicating the percentage of effect that air pressure (altitude is air pressure, too) has on jetting. . . . It's easily worth $5." —Cycle News